SCIENCE IN SWIMMING III

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Akademia Wychowania Fizycznego we Wrocławiu

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Edition I

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PREFACE

The symposium "Science of Swimming" is already 10 years old. It changes together with its participants and scientific developments. Swimming is developing thanks to the commitment and passion of many researchers. Athletes achieve ever better results and people in general swim better and better. Some of us have been interested in the history of swimming and have committed to its study; others have embarked on studies in the field related to interference in communication (in a changing environment); other groups of researchers deal with adaptation to water environment, while some of us are interested in technique and its biomechanical analysis or in safety. The scope of interest related to swimming is vast and aspects related to swimming are found in many fields of science. Humans do not only lose weight while swimming; they may also lose everything if they do not exercise proper caution. It seems that the role of this symposium is the transfer of knowledge from research labs to lecture halls. Therefore the participation of students in our symposium is not accidental. They are to become the beneficiaries of know-how and findings developed in laboratories and in the field. Exchange of thought in our symposia have always been accompanied by lectures by renowned academics. This allows all the participants and students from all parts of the World to have access to trends, applications and the use of knowledge in practice. We will publish books that will provide all interested with the latest developments in science. The selection of the best publications is a great opportunity to see how science and new trends develop. Selected authors will also authoritatively point new directions for some of us and help blaze new trails for other academics. The symposium is flourishing and it will be developing further so that our publications may become a physical evidence of the state of the art on swimming.

We would like to express our sincere thanks to the reviewers of this book: Professor Tadeusz Bober and Professor Robert Keig Stallman for their hardworking and great contribution in the process of the creation of *Science in Swimming III*. We take also this opportunity to thank all the authors who have contributed to these papers.

Editors

CHAPTER I

DIDACTICS IN SWIMMING

≋ SCIENCE IN SWIMMING III, 2011, 8–13

The history of swimming research – past and present

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Between 1538, the date of the first book specifically dedicated to swimming written by Wynmann, and 1970, the date of the first International symposium on biomechanics and medicine in swimming (organized by J. Lewillie and J.P. Clarys in Brussels), the art of swimming can be described as both the result of the swimmer's experience, and technical aspects discovered by scientists. From 1970 up to 2008, as the level of national and international swimming become more competitive and professional, sport practitioners turned to science to help decide which methods were more effective than others. Today, and specifically seen in this book, swimming in humans is an important topic of scientific research. Thus, the purpose of this non-exhaustive historical review was to analyze the emergence, evolution and state of swimming science and research from 1538 to 2008.

FROM 1538 TO 1970

Numerous written works and films on swimming can explain the technical and teaching concepts[1]. The different texts available change from a gymnastic, military and utilitarian form of swimming, up until the First World War more in the direction swimming as sport form thereafter. Swimming has become an important cultural phenomenon, where teaching is complex and differs in relation to biomechanical concepts of the same period. Among the different authors, and more specifically in France, one can differentiate:

– The humanist instructors[2]: they were clerics, intellectuals and professionals. Swimming had a utilitarian and educational form. The objectives were a complete education and an adaptable swimmer.

1 Pelayo P., From "De arte Natandi" to the science of swimming: Biomechanical and pedagogical conceptions in swimming, [in:] Chatard J.C. (ed.), Biomechanics and Medicine in Swimming IX, Université de Saint-Etienne, Saint-Etienne, 2003, pp. 1–7.

2 Thévenot M., L'art de nager, avec des essais pour se baigner utilement, Librairie Lamy, Paris, 1781; De Fontenelle J., Manuel des nageurs – Nouveau manuel complet: des nageurs, des baigneurs, des fabricants d'eau minérale, et des pédicures, Encyclopédie Roret, Paris, 1848; Roger R., Traité de natation ou l'art de nager en rivière et en mer, Editions H. Delarue, Paris, 1881.

- The military[3]: swimming is considered as a strategic weapon. Two aspects were pursued: a hygienic and disciplined activity.
- The "Gymnasiarque"[4]: swimming is a gymnastic art. It consisted of learning positions in a group activity involving discipline[5].
- Engineers: technology and the use of devices was more important than the technical solutions themselves. Floating and propelling devices (from the stool to the swimming-teaching machine) involved a real educational renunciation.
- Doctors[6]: swimming was an additional aid to health and had the beneficial effects of baths and physical exercise.
- Swimming teachers[7]: they had commercial ambitions and published progressive learning techniques in order to obtain an institutional recognition.
- Sportsmen[8]: they appeared at the beginning of the 20th century with the sports phenomenon. The goal was new: competition.

Moreover, the evolution of biomechanical knowledge and regulation constraints were put forward to explain balance, breathing and propulsion changes in the modern swimming strokes[9]. In the past 100 years, and in relation to the development of competition, swimming strokes have been greatly refined because swimmers throughout history have experimented with swimming faster in different ways.

On the one hand, swimmers experimented by trial and error and watching others but few champions had the background necessary to explain the mechanical action of the strokes. The evolution of technical solutions in swimming has been the result of a permanent research for speed. From 1850 to 1910, the most decisive landmark was when the first competitors transferred from breast stroke, to the front crawl. In 1902, Richard Cavill set a world record in the 100 yards, by swimming the whole distance in the front crawl. On this date, the crawl became the fastest stroke. The front crawl stroke is very efficient because the streamlined position of the body and arm recoveries out the water, decrease the drag resistance, while the alternative arm actions guarantee the continuity of the propulsive forces. Between 1912 and 1932, the evolution of balance (and particularly breathing changes) mainly explain the improvement of performances. At the Olympic Games in Stockholm in 1912, Duke Kahanamoku adopted a streamlined position, and in Paris (1924) Johnny Weissmuller broke the mythical one minute barrier for the 100 m. In his book[10], he explained that, "The instinctive thing for a beginner

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3 Courtivron L. de, De la natation et son application – l'art de la guerre, Imprimerie Anthelme Boucher, Paris, 1824.
4 Defrançois C., La locomotion dans l'eau. Principes élémentaires de natation, Imprimerie Mato-Braine, Reims, 1870; Verdonck L., Traité pratique de natation, Editions Le Bigot Frères, Lille, 1896.
5 Beulque P., Descarpentries P., Méthode de natation adoptée par la FFNS, Imprimerie Georgres Frères, 1922.
6 Defrançois, op. cit.
7 Clucague C., La natation apprise en trois exercices d'application par la ceinture Porte-Bouées, Imprimerie G. Gounouilhou, 1900; Beulque, Descarpentries, op. cit.
8 Beulque, Descarpentries, op. cit.; De Coubertin P., La gymnastique utilitaire – Sauvetage-défense-locomotion, 1905.
9 Pelayo, op. cit.
10 Weissmuller J., L'art de nager le crawl, M.P. Tremois, Paris, 1931.

to do is to hold his breath. As soon as he learns to overcome this, half his fight is won, and he is ready for the finer points of swimming" and "After improving my breath control,..., where a mile a day had exhausted me completely, I began to do a mile and a half a day with greater ease". In 1926, Gertrude Ederle broke the record in the crossing the Channel, doing the crawl over the complete distance. On this date, the crawl became the most economical stroke.

On the other hand, the first scientific analysis conducted by Dubois-Reymond in 1905 and 1927[11] as well as Cureton in 1930[12] helped produce more varied strokes, greater speeds and a better understanding of propulsion through water. This, along with Karpovitch in 1933[13], marked the beginning of research in stroke mechanics and swimming physiology exercise. In 1928, Armbruster first filmed swimmers under water to study strokes. The Japanese also photographed and studied world-class athletes, using their research to produce a swim team that dominated the 1932 Olympic Games. Then, researchers[14] such as Dr. James Edward Counsilman[15] focused both on the forces that act on a body moving through the water and on the exercise physiology applied to swimming, to better define training programs. Owing to their pioneering and painstaking work stroke mechanics, teaching and training methods in swimming were revolutionized.

FROM 1970 TO 2008

Today, the science of swimming is highly developed, and helps coaches to improve swimmers' times in competition. From 1970 to 2008, the level of national and international swimming has become more competitive and professional, and swimming science has become one of the keys of swimming success. In the second part of this paper, the purpose of this historical review is to analyze the evolution and state of scientific swimming research. Nevertheless, scientific studies have led to high levels of frustration for coaches due to the inability of a single approach such as physiological, biomechanical, psychological... to provide the answer as quickly as possible. However, determining the most correct answer in the training process is dependent upon the weight of the scientific background available at a specific moment. The results of scientific studies, along with results from practical experiences, can help to determine the best answer, as shown by Troup[16] through the concept of the learning continuum:

[11] Defrançois, op. cit.; Du Bois-Reymond R., Zur physiologie des schwimmens, *Arch Anat Physiol Abt Physiol*, 1905, no. 29, pp. 252–278.
[12] Cureton T.K., Mechanics and kinesiology of swimming, *Res Quart*, 1930, no. 1, pp. 87–121.
[13] Karpovitch P.V., Water resistance in swimming, *Res Quart*, 1933, no. 4, pp. 21–28.
[14] Klein W.C., Test for the prediction of body resistance in water. Master's thesis, University of Iowa, Iowa City, 1939; Jaeger L.D., Resistance of water as limiting factor of speed in swimming. Master's thesis, University of Iowa, Iowa City, 1937.
[15] Counsilman J.E., An analysis of the application of force in two types of crawl strokes. Doctoral dissertation, University of Iowa, Iowa City, 1951.
[16] Troup J.P., The continuum of applied swimming science, [in:] Troup J.P., Hollander A.P., Strasse D., Trappe S.W., Cappaert J.M., Trappe C.A. (eds.), Biomechanics and Medicine in Swimming VII, E & FN Spon, London, 1996, pp. 3–13.

Scientific results ⟹ Applications ⟹ Evaluation ⟹ Improved training

However, the scientific process is simultaneously and mainly influenced by the quality of the experimental design, the status of the experimental and control groups and the specificity of the test markers affecting training, performance or experimental results. Following a similar approach to Troup[17], three degrees of control can be distinguished in the current contents of publication:

1. Basic studies and applied studies, where interventions on animal or swimming material are tested, with a lack of external and influencing factors. These papers are found in the most respected peer reviewed journals with an impact factor higher than 4. However, they are very difficult to numerate because they do not correspond to specific key words such as swimming or training.
2. Descriptive studies where characteristic and typical responses during swimming exercise in humans are scientifically measured, and are mostly published in scientific journals, with an impact factor lower than 3.5.
3. Practical and field studies, where findings emerge from a practical and useful point of view, while still maintaining scientific integrity and controls. Nevertheless, the results are more often linked to a specific context of training and population. They cannot be extended to general and scientific concepts, and are published in professional national or international journals applied to swimming. Indeed, these studies do not tightly control confounding factors such as compliance between coach and athlete, but provide practical information derived from levels 1 and 2 of scientific knowledge. These publications are very often written in different national languages and difficult to enumerate.

Nevertheless, the first two levels of publications are today very large and diversified. Clarys in 1996[18], that by the mid 1990's, there were 685 peer reviewed papers on swimming and in 2006 Keskinen[19], using EBSCOhost Research Databases and Sport Discus, observed 16,067 papers on swimming, when the time line was kept unlimited, but excluded animal experiments. Over the last decades, the increase in these publications (essentially level 2) reflects the growing interest of researchers to carry out studies in situ, and can also indicate that these researchers are in part, solicited and financed by the national swimming federations. For most of the great nations, the later have developed their own research structures or partnerships with private or university laboratories.

Indeed we can notice on Fig. 1, an increase of the number of scientific papers (level 1 and 2) published during the last four decades, related to swimming performance in humans. Systematic literature searches were performed for the years 1970–2005, and calculated every four years, utilizing PubMed databases and introducing specific key words such as: swimming, performance, human and com-

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17 Ibid., pp. 3–13.

18 Clarys J.P., The historical perspective of swimming science, [in:] Troup J.P., Hollander A.P., Strasse D., Trappe S.W., Cappaert J.M., Trappe C.A. (eds.), Biomechanics and Medicine in Swimming VII, E & FN Spon, London, 1996, pp. xi–xxiv.

19 Keskinen K.L., State of the art on swimming physiology and coaching practice. Bridging the gap between theory and practice, *Rev Port Cien Desp*, 2006, vol. 6, no. 2, pp. 285–287.

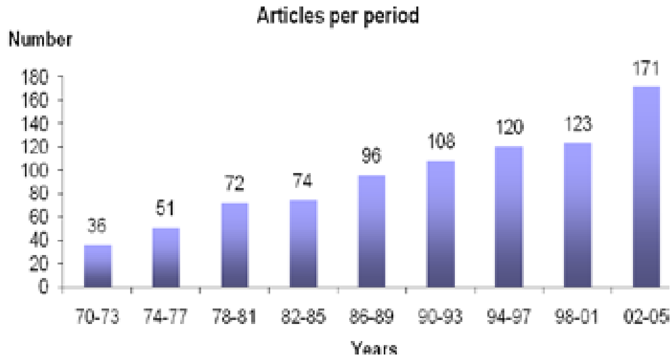

FIGURE 1. Evolution of specific papers related to swimming and referenced in PubMed data base from 1970 to 2005

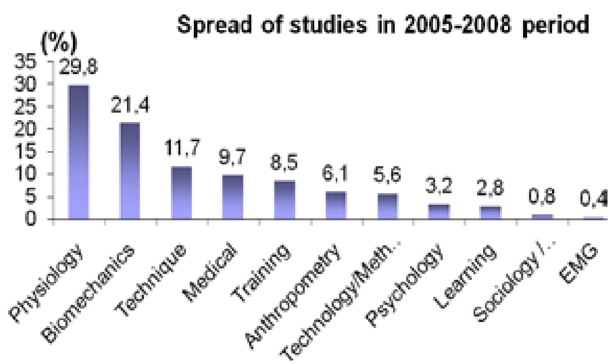

FIGURE 2. Different scientific domains investigated in the 182 specific papers (expressed in %) related to swimming and referenced in PubMed data base from 2005 to 2008

petition; and excluding papers about pregnant women, toddlers, scuba diving, infections, therapic properties of water, etc. Likewise excluded were: triathlon, water polo, synchronized swimming and diving, none of which are specifically related to swimming.

Moreover, and as shown in Fig. 2, the different scientific fields investigated in the specific 182 papers related to swimming, and referenced in the PubMed data base from 2005 to 2008, are very diversified and can be classified in Biomechanics, Physiology, Technique, EMG, Medical, Psychology, Sociology and History, Learning, Technology and Methodology, Training and Anthropometry.

These three levels of swimming research and publications are complementary as well as necessary, to improve the way in which the training process is carried out, and to provide a service to coaches and swimmers. In fact, an appropriate balance of the three levels of swimming research can lead to the enhancement of a scientific approach of the swimming teaching and training process. The different national and international congresses such as those of the World Congress of Medical and Scientific aspects of aquatic sports (FINA), the well-known International Symposiums on Biomechanics and Medicine in Swimming (BMS), and more specifically the **5th International Symposium of Science & Swimming in Wrocław** (Poland) can give us a wealth of research, unique and unprecedented, in the world of sports. In consideration of the multifaceted character of swimming science, the aim of these symposia is to provide a forum for scientists and students from all fields of swimming research, by offering state-of-the-art views in applied and basic sciences related to swimming sports, teaching, exercise and health. The topics which will be covered are not only biomechanics and medicine, but also many more aspects of swimming science:

- *The biological and physical science of swimming*: physiology, biomechanics, anatomy, electromyography, anthropometry, body composition, physics, bioenergetics, ergonomics;
- *The medical science of swimming*: clinical medicine, public health, injury prevention;
- *The educational science of swimming*: pedagogy, didactics, motor learning;
- *The social science of swimming*: psychology, sociology, anthropology, history, philosophy;
- *Health and physiotherapy;*
- *Leisure in water environment;*
- *Problems related to disabled swimmers.*

CONCLUSIONS

Science plays an important role in the understanding and development of swimming performance. Swimming research can play an important role in indentifying factors of performance and developing methods to improve them. The added benefit of research results is information that can enhance educational and training materials and programs. Moreover, a practical sport science program can also be the background topic of research designed to model and evaluate new concepts in training. Swim researchers also contribute to initiating new techniques, drills, and teaching and training methods based on scientific principles. Furthermore, it must be understood by both the scientist and the swimming coach that today, research study and swimming success is linked and dependant on, a scientific continuum. The greatest nations, vying for places on the swimming podiums at the highest level, have understood and financed research structures and athlete study centers, allowing coaches and researches to work together in a fruitful way.

≋ SCIENCE IN SWIMMING III, 2011, 14–21

The influence of training with reduced breathing frequency on performance of an even front crawl swum to exhaustion

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INTRODUCTION

The activity of swimming, in relation to dry land activities, is strictly technique-dependent breathing[1]. Breathing in swimming is synchronised with swimming strokes. In all swimming techniques, except in backstroke, expiration takes place under water and, accordingly, against greater resistance than in air. Furthermore, breathing frequency has to be in accordance with the stroke rate. Swimmers could also manipulate with different breathing patterns during front crawl swimming. Usually, they take breaths every second or third stroke cycle. However, they could reduce breathing frequency by taking breath every fourth, fifth, sixth or eighth stroke cycle. Reduced breathing patterns are often used during the final part of the competition races, when swimmers try to finish as fast as possible. Due to simple regulation of breathing during exercise, reduced breathing frequency (RBF) has often been used during regular swimming training, since 1970's. It has been thought that, by limiting inspired air, a reduction of oxygen available for muscular work would result, and therefore cause, muscle hypoxia. In addition, these conditions would increase anaerobic glycolysis and hence improve lactic acid tolerance[2]. For that reason, it was named as "hypoxic training"[3].

In some previous studies, swimmers reduced their breathing frequency during tethered front crawl swimming[4], during front crawl interval sets[5], during front

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1 Holmér I., Stein E.M., Saltin B., Ekblom B., Astrand P.O., Hemodynamic and respiratory responses compared in swimming and running, *Journal of Applied Physiology*, 1974, no. 37, pp. 49–54.

2 Kedrowski V., Hypoxic training, *Swimming Technique*, 1979, no. 13, pp. 55–66.

3 Maglischo E.W., Swimming fastest, Human Kinetics, Leeds, 2003.

4 Dicker S.G., Lofthus G.K., Thornton N.W., Brooks G.A., Respiratory and heart rate responses to controlled frequency breathing swimming, *Medicine and Science in Sport and Exercise*, 1980, no. 1, pp. 20–23; Peyrebrune M., Robinson J., Lakomy H., Nevill M., Effects of controlled frequency breathing on maximal tethered swimming performance, [in:] Chatard J.C. (ed.), Biomechanics and Medicine in Swimming IX, Université de Saint-Etienne, Saint-Etienne, 2003, pp. 289–294; Town G.P., Vanness J.M., Metabolic responses to controlled frequency breathing in competitive swimmers, *Medicine and Science in Sport and Exercise*, 1990, no. 22, pp. 112–116.

5 Holmér I., Gullstrand L., Physiological responses to swimming with a controlled frequency of breathing, *Scandinavian Journal of Sports Science*, 1980, no. 2, pp. 1–6.

crawl swimming at OBLA (the onset of blood lactate accumulation) velocity[6] and during maximal front crawl swimming[7]. These studies were unable to demonstrate hypoxia conditions by analysing the air expired during the exercise[8] or by measuring capillary blood sampled after the exercise[9]. Considering obtained higher partial pressure of CO_2 obtained, they suggested that this kind of training is more likely "hypercapnic training".

Due to the technical limitations of measuring respiratory and blood parameters during swimming, the idea of RBF during exercise on land has also been investigated; examples include cycle ergometry[10], and treadmill running[11]. These studies confirmed marked hypercapnia as a result of RBF during exercise. In addition, hypoxia was also obtained by measuring capillary blood sampled and oxygen saturation (SaO_2) during exercise with RBF. However, all of the reported studies investigated the acute effects of RBF during exercise. According to hypercapnia obtained as a result of RBF during exercise, it could be suggested that this kind of training could improve tolerance to high alveolar CO_2[12] and consequently adapt swimmer to swim with fewer breaths. The latter suggestion was recently confirmed[13]. Swimmers decreased their breathing frequency during a maximal 200 m front crawl, with an optional breathing pattern, due to the training with RBF (taking a breath every fourth stroke cycle) during front crawl swimming. Lower breathing frequency may have some biomechanical advantage on swimming performance[14] and enable faster swimming[15]. This could be an important advantage during shorter events and during the finish part of competitive races. Therefore, training with RBF is

6 Kapus J., Ušaj A., Kapus V., Štrumbelj B., The influence of reduced breathing during swimming on some respiratory and metabolic values in blood, *Kinesiologia Slovenica*, 2002, vol. 8, no. 1, pp. 14–18.

7 Kapus J., Ušaj A., Kapus V., Štrumbelj B., The influence of reduced breathing during swimming on some respiratory and metabolic values in blood, *Kinesiologia Slovenica*, 2003, vol. 9, no. 1, pp. 12–17.

8 Dicker, Lofthus, Thornton, Brooks, op. cit.; Holmér, Gullstrand, op. cit.; Town, Vanness, op. cit.

9 Kapus, Ušaj, Kapus, Štrumbelj, op. cit. (2002); Kapus, Ušaj, Kapus, Štrumbelj, op. cit. (2003).

10 Kapus J., Ušaj A., Kapus V., Some metabolic responses to reduced breathing frequency during constant load exercise, *Medicina Sportiva*, 2010, vol. 14, no. 1, pp. 13–18; Sharp R.L., Williams D.J., Bevan L., Effects of controlled frequency breathing during exercise on blood gases and acid-base balance, *International Journal of Sports Medicine*, 1991, no. 12, pp. 62–65; Yamamoto Y., Takei Y., Mutoh Y., Miyashita M., Delayed appearance of blood lactate with reduced frequency breathing during exercise, *European Journal of Applied Physiology*, 1988, no. 57, pp. 462–466.

11 Matheson G.O., McKenzie D.C., Breath holding during intense exercise: arterial blood gases, pH, and lactate, *Journal of Sports Medicine and Physical Fitness*, 1988, no. 64, pp. 1947–1952.

12 Dicker, Lofthus, Thornton, Brooks, op. cit.; Peyrebrune, Robinson, Lakomy, Nevill, op. cit.

13 Kapus J., Ušaj A., Kapus V., Štrumbelj B., The influence of training with reduced breathing frequency in front crawl swimming during a maximal 200 metres front crawl performance, *Kinesiologia Slovenica*, 2005, vol. 11, no. 2, pp. 17–24.

14 Lerda R., Cardelli C., Chollet D., Analysis of the interactions between breathing and arm actions in the front crawl, *Journal of Human Movement Studies*, 2001, no. 40, pp. 129–144; Chatard J.C., Collomp C., Maglischo E., Maglischo C., Swimming skill and stroking characteristics of front crawl swimmers, *International Journal of Sports Medicine*, 1990, no. 11, pp. 156–161.

15 Pedersen T., Kjendlie P.L., The effect of the breathing action on velocity in front crawl sprinting, *Portuguese Journal of Sport Science*, 2006, no. 6, supl. 2, pp. 75–77.

suggested mainly for sprinters[16]. However, the influence of training with RBF on longer distance performance is still unclear. An even front crawl, swum to exhaustion, performed at 90% of velocity and reaching a maximal 200 m, was used as a test swim in this study. Therefore, the purpose of the present study was to compare the effects of high intensity interval swimming training with different breathing frequencies, on swimming to exhaustion with usual and RBF. Due to obtained acute effects of exercises obtained with different breathing frequencies, it is hypothesized that a training swimming under different breathing conditions, will induce specific training adaptations. Training with RBF will effect a subject's performance when swimming a test to exhaustion under RBF conditions. On other hand, such a training adaptations are not expected after the swimming training with usual breathing.

METHODS

Ten voluntary males (age: M = 16.6 yrs, SD = 1.8 yrs; height: M = 180 cm, SD = 7 cm; weight: M = 70 kg, SD = 7 kg) participated in the study after being informed of the associated risks and giving their written informed consent. None of the subjects were smokers and were free of respiratory disease at the time of the study. The study was approved by the University's Research Ethics Committee. The subjects were recreational level swimmers. They have trained for at least five years. However, they had never more than three training sessions per week. The intensity of their training has been sub-maximal. The goal of their training was mainly to improve swimming technique. Therefore they were well-skilled swimmers, without experiences with competitive and maximal intensity swimming. Their average time in a maximal 200 m front crawl swim was 158 s, measured in a pre-training test. They were divided into two groups: control (C group) and experimental (EXP group).

The subjects initially performed three tests on a different day: a maximal 200 m front crawl swim, and two swims, swum to exhaustion, with different breathing frequencies. The subjects then undertook a four-week training program. After the training, the subjects performed the same tests as before the training sessions. The intensity, breathing frequency and stroke rate during the swimming to exhaustion, at post-training testing, were similar to those which as were obtained at pre-training testing. The swimming tests and training were performed in a 25 m indoor pool with a water temperature of 27°C.

Preliminary testing. Subjects initially performed a maximal 200 m front crawl swim. From velocity obtained at this test, the velocity of swimming to exhaustion tests and training was chosen for each subject.

Swimming to exhaustion. Subjects performed sub-maximal front crawl swimming twice: first, by taking a breath every two strokes (B2), and second by taking a breath every four strokes (B4). At both tests, the subjects swam as long as possible at fixed, pre-determined velocity. That was 90% of velocity, reached in a maxi-

[16] Maglischo, op. cit.

mal 200 m front crawl swim. To keep even pace, each subject was informed of intermediate times during swimming. Stroke rate at B4 was the same as it was at B2, since we knew that swimmers reduced swimming velocity and/or increased stroke rate, when the need to breathe become critical during swimming with RBF[17].

Training program. Both groups were given four weeks swimming training five times per week. Nineteen training sessions were undertaken. Each training session consisted of 600 m of warming up, followed by an interval front crawl set (7 × 100 m with 3 min of recovery or 7 × 125 m with 3 min and 30 s of recovery or 5 × 150 m with 4 min of recovery or 4 × 175 m with 4 min and 30 s of recovery). The intensity was determined by using the maximal velocity of a 200 m front crawl swim. During each swim the breathing pattern differed between the C group and the EXP group. The C group was taking a breath every second stroke cycle, the EXP group was taking a breath every fourth stroke cycle.

Swimming time per each 25 m distances was measured by using a CASIO digital stopwatch (Casio Electronics Co., London, United Kingdom). The elapsed time for five complete one arm stroke cycles, during an approximate 12 m section of each pool length, was measured to calculate stroke rate (stroke cycles × s^{-1}). The breathing frequency was calculated by dividing the number of breaths with the time, which were both measured during the swimming test. The stroke rate and breathing frequency were measured for each 25 m.

Measurement included the measure of lactate concentration ($[LA^-]$) and the parameters of blood acid-base status (Pco_2, Po_2, pH and $[HCO_3^-]$) before and during the first minute after the swimming test. Capillary blood samples for measuring Pco_2, Po_2 and pH were taken via a micro-puncture from a hyperemied earlobe. Earlobe capillary blood was arterialized by the application of hyperemic cream (Finalgon, Boehringer-Ingelheim, Reims, France) at least 20 min before the first capillary sample. Earlobe samples were collected in heparinized glass capillary tubes and introduced into a blood gas analyser ABL5 (Radiometer, Copenhagen, Denmark) for gas analysis at 37°C. The blood gas analyser also automatically calculated $[HCO_3^-]$. Blood samples (10 μl) for measuring $[LA^-]$ were diluted in a haemolizing solution and analysed using the MINI8 (LANGE, Germany) photometer. Capillary blood samples (60–80 μl) were taken by micro-puncture from a hyperemied earlobe. Blood samples for measuring $[LA^-]$ were diluted in a LKM41 lactate solution (Dr. Lange, Berlin, Germany) and analyzed using the MINI8 photometer (Dr. Lange, Berlin, Germany).

The results were presented as means and standard deviations (M, SD). The paired T test was used to compare the pre- and post-training data. The training effects of different breathing patterns during front crawl swimming (differences between groups at post-training testing) obtained at swimming tests were analyzed using Analysis of covariance (ANCOVA).

[17] Town, Vanness, op. cit.

RESULTS

The data in Tab. 1 shows that both groups swam the maximal 200 m front crawl after the training, significantly faster then before the training ($p < 0.05$ and 0.01). The improvement in the time obtained at this test was significantly greater in the EXP group than in the C group ($p < 0.05$). In addition, the C group extended the swimming distance at B4 with the training ($p < 0.05$).

TABLE 1. Comparisons of the time of a maximal 200 meters front crawl and the distances of B2 and B4 obtained at pre- and post-training testing

Parameter	Group	Pre-training	Post-training	
Time (s) of maximal 200 meters front crawl	C	161.1 ± 8.2	157.1 ± 8.1**	†
	EXP	154.7 ± 14.6	148.5 ± 10.9*	
Swimming distance (m) of B2	C	580 ± 148	670 ± 168	
	EXP	440 ± 119	450 ± 79	
Swimming distance (m) of B4	C	380 ± 91	570 ± 164*	
	EXP	375 ± 61	420 ± 57	

significant training effect (paired T test): * $p < 0.05$ and ** $p < 0.01$;
significant differences between groups at post-training testing (ANCOVA): † $p < 0.05$.

TABLE 2. Comparisons of the blood parameters obtained at B2 (before and after swimming) at pre- and post-training testing

Parameter	Group	Pre-training	Post-training
pH before	C	7.40 ± 0.03	7.43 ± 0.03
	EXP	7.44 ± 0.01	7.40 ± 0.03
pH after	C	7.26 ± 0.03	7.28 ± 0.03*
	EXP	7.19 ± 0.04	7.22 ± 0.04
Pco_2 (kPa) before	C	4.6 ± 0.2	5.0 ± 0.1
	EXP	4.6 ± 0.3	5.0 ± 0.3
Pco_2 (kPa) after	C	4.6 ± 0.5	4.8 ± 0.5
	EXP	4.9 ± 0.7	5.1 ± 0.4
Po_2 (kPa) before	C	10.7 ± 0.5	9.7 ± 1.2
	EXP	10.8 ± 1.7	9.6 ± 0.3
Po_2 (kPa) after	C	10.9 ± 0.5	11.0 ± 0.5
	EXP	10.9 ± 1.7	11.8 ± 2.5
$[HCO_3^-]$ (mmol/l) before	C	21 ± 1.8	24 ± 1.8
	EXP	23 ± 1.6	22 ± 2.3
$[HCO_3^-]$ (mmol/l) after	C	15 ± 1.3	16 ± 0.5
	EXP	13 ± 1.4	15 ± 1.3
$[LA^-]$ (mmol/l) before	C	3.1 ± 1.1	2.4 ± 0.7
	EXP	2.0 ± 0.6	2.9 ± 1.0
$[LA^-]$ (mmol/l) after	C	10.1 ± 1.1	9.4 ± 0.8
	EXP	12.1 ± 0.9	11.9 ± 2.2

significant training effect (paired T test): * $p < 0.05$.

Regardless of type of comparison (the pre- and post-training data or the training effect), there were almost no significant differences in values of blood parameters obtained at B2 (Tab. 2).

TABLE 3. Comparisons of the blood parameters obtained at B4 (before and after swimming) at pre- and post-training testing

Parameter	Group	Pre-training	Post-training	
pH before	C	7.41 ± 0.03	7.43 ± 0.01	
	EXP	7.42 ± 0.03	7.42 ± 0.02	
pH after	C	7.28 ± 0.03	7.28 ± 0.04	
	EXP	7.17 ± 0.06	7.21 ± 0.04	
Pco_2 (kPa) before	C	4.6 ± 0.4	5.0 ± 0.2	
	EXP	4.9 ± 0.2	5.1 ± 0.3	
Pco_2 (kPa) after	C	5.2 ± 0.6	5.5 ± 0.4	
	EXP	5.9 ± 1.0	6.0 ± 0.2	
Po_2 (kPa) before	C	11.1 ± 1.3	10.5 ± 0.5	
	EXP	10.0 ± 0.6	10.1 ± 0.6	
Po_2 (kPa) after	C	10.9 ± 0.6	11.2 ± 0.6	
	EXP	10.6 ± 0.9	10.6 ± 1.0	
$[HCO_3^-]$ (mmol/l) before	C	22 ± 1.8	24 ± 0.8	
	EXP	24 ± 1.8	24 ± 1.9	
$[HCO_3^-]$ (mmol/l) after	C	18 ± 1.1	18 ± 0.5	*
	EXP	16 ± 1.3	17 ± 1.1	
$[LA^-]$ (mmol/l) before	C	3.3 ± 1.9	1.5 ± 0.2	
	EXP	1.8 ± 0.6	2.5 ± 1.7	
$[LA^-]$ (mmol/l) after	C	7.7 ± 1.9	6.2 ± 0.8	**
	EXP	10.4 ± 1.8	10.4 ± 0.2	

significant differences between groups at post-training testing (ANCOVA):
* $p < 0.05$ and ** $p < 0.01$.

Tab. 3 demonstrates that, there were significant different effects of training with different breathing frequency on $[HCO_3^-]$ and $[LA^-]$ values after B4 ($p < 0.05$ and $p < 0.01$). However, there were no significant differences in other values of blood parameters obtained at B4.

DISCUSSION

The purpose of the present study was to compare the effects of high intensity interval swimming training with different breathing frequencies (usual breathing by taking a breath every second stroke cycle and RBF by taking a breath every fourth stroke cycle) on swimming to exhaustion with usual breathing and with RBF. Due to training characteristics, it was expected that training with both breathing patterns brought about an improvement in swimming velocity in maximal 200 m front crawl performance. Detailed discussion and conclusions on this were published in Kapus et al.[18]. However, the training effects on subjects' even swimming performance were less significant.

Regardless of breathing frequency during the training, there was no significant influence on B2 performance. There could be many reasons for this. Although the short duration of the training could be the most important reason. In addition, the main goal of training was to improve maximal 200 m front crawl performance. Therefore, the training of both groups included intense interval sets with long sprints and long to medium rest intervals. This kind of training is proposed to adopt the swimmer to severe acidosis[19]. Duration of exercises at interval sets were between 79 (± 6) s (7 × 100 m) and 138 (± 10) s (4 × 175 m). However, the exercises at B2, which lasted from 300 to 840 s, were considerably longer. Thus, the contributions of each energy system differed between the testing and training exercises. According to Maglischo[20], anaerobic metabolism could be the major contributor of energy during swimming interval sets. On the contrary, aerobic metabolism supplied most of energy at B2.

The results obtained at B4 were a surprise. In this test RBF was used during even front crawl swimming to exhaustion. However, the subjects who trained with this kind of breathing did not extend the swimming distances. On the contrary, C group, who trained with usual breathing during swimming, swam significantly longer (570 ± 164 m) at the post- then the pre-training (380 ± 91 m) testing. Considering the analysis of the individual results and the results of some previous studies, at least two reasons could be suggested for such training effects. Higher Pco_2 is the main factor that induced earlier acidosis during exercise with RBF[21]. In the present study, one swimmer in the EXP group and three swimmers in C group, had higher post-training values of Pco_2 after B4 in comparison with values obtained at the pre-training testing. It seemed that the EXP group increased the pulmonary ventilation, and thus the elimination of carbon dioxide with the training. On the contrary, the training effect on C group could also be an adaptation to higher Pco_2. This suggestion is in accordance with the results of Holmér and Gullstrand[22]. They concluded that experienced swimmers tolerated higher alveolar Pco_2. Due to strictly technique-dependent breathing during swimming, swimming training with usual non reduced breathing, could already induce such an adaptation. In addition, there were significant differences between the groups in [LA^-] after B4, at post-training testing (Tab. 3). At the C group, values of this parameter decrease insignificantly with training. On the contrary, when comparing pre-and post-training data, [LA^-] was almost unchanged in the EXP group. Therefore, it could be presumed that RBF during front crawl training induced a smaller increase (or no increase at all) in lactate exchange and removal abilities in comparison with usual breathing during front crawl training. Lactate is produced in the cytoplasm of muscle cells and consumed by mitochondria that have

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18 Kapus, Ušaj, Kapus, Štrumbelj, The influence of training…
19 Maglischo, op. cit.
20 Ibid.
21 Kapus, Ušaj, Kapus, Štrumbelj, The influence of reduced…, 2003.
22 Holmér, Gullstrand, op. cit.

enzymatic apparatus to take up and oxidize lactate. According to the results of some previous studies, RBF during exercise may influence on this process in two ways. Yamamoto et al.[23] suggested that inhibition of lactate efflux from working muscle, as a consequence of hypercapnia and acidosis, occurred during exercise with RBF. In addition, lactate is removed mainly by oxidation. In the present study oxygen uptake during swimming was not measured. However, in some previous studies, RBF during exercises induced lower oxygen uptake in comparison with the usual breathing conditions[24].

The present study is the first to our knowledge that has examined the influence of training with RBF on subject's performance. However, the presented research problem has not been solved. The results of our study are insufficient to show a clear picture of adaptation of training which is often used during regular swimming practice. Indeed, the water environment is inappropriate for direct measurement of respiratory and blood parameters during swimming. Therefore, the question is whether the measurements of blood parameters, taken after the end of the swimming, test reflected the conditions which appeared during the swimming test. A recent study has shown that, measurements of blood gas parameters taken 15 s after cessation of exercise with RBF, did not reflect the changes in Po_2 seen during exercise[25]. To overcome this problem, the idea of training with RBF should be further investigated during the course of some type of on-land activity, such us ergometric cycling or exercise on a swimming bench.

CONCLUSIONS

It seemed that the training used was too short and inappropriate to induce significant improvement in subject's performance. In addition, it was presumed that RBF during front crawl training induced a smaller increase (or no increase at all) in lactate exchange and removal abilities in comparison with usual breathing during front crawl training. Considering the possible training adaptation of usual breathing during front crawl training (adaptation to higher Pco_2 and slower, less dramatic changes in blood parameters during swimming) this could be a reason for improvement of C group in B4. However, this research problem needs to be further studied.

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23 Yamamoto, Takei, Mutoh, Miyashita, op. cit.

24 Holmér, Gullstrand, op. cit.; West S.A., Drummond M.J., VanNess J.M., Ciccolella M.E., Blood lactate and metabolic responses to controlled frequency breathing during graded swimming, *Journal of Strength and Conditioning Research*, 2005, no. 19, pp. 772–776; Yamamoto, Takei, Mutoh, Miyashita, op. cit.; Stager J.M., Cordain L., Malley J., Stickler J., Arterial desaturation during arm exercise with controlled frequency breathing, *Medicine and Science in Sport and Exercise*, 1985, no. 17, p. 227.

25 Kapus J., Ušaj A., Kapus V., Štrumbelj B., The difference in respiratory and blood gas values during recovery after exercise with spontaneous versus reduced breathing frequency, *Journal of Sports Science and Medicine*, 2009, vol. 8, no. 3, pp. 452–457.

≋ SCIENCE IN SWIMMING III, 2011, 22–30

Application of kinematic parameters of motion in teaching small children to swim

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INTRODUCTION

In teaching and perfecting motion activities, an evaluation of the movement process is most frequently based on visual observations, where the main criterion of the evaluation is the accuracy of the motion. In treating the motion technique as a means of performing the activity, we can describe a given activity using kinematic values. Thus, an effective model of teaching motion activities should include a biomechanical analysis of the said activities. The effects of biomechanical research, supplemented by the experience of educators and physical education teachers, raise the level of knowledge about the principles of human motor functions[1]. Teaching new movement activities in such a manner, allows for a formulation of definite methodological means which will increase the effectiveness of the action.

One of the positive possibilities of human movement behaviours is locomotion. The term *locomotion* has come to mean; well coordinated, automatic motion activity, making the body move in a given space[2]. Locomotion activities can be divided into particular phases, repeating themselves rhythmically in such a way that the end of a movement on one side, is the beginning of a movement on the other side, and thus every type of locomotion requires the performance of phase movements. In the case of basic human locomotion movements on the ground, such as walking or running, there is a *global locomotion pattern*[3]. As the range of the above mentioned motion activities (performed on the ground) have a very precise criterion, this allows for the evaluation of the movement's accuracy, both in the ontogenetic process, as well as in the rehabilitation process. In the case of locomotion in water, the process of gaining new movement skills is mainly based on subjective criteria[4]. The objective biomechanical motion criteria, which allow

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1 Schmidt R.A., Wrisberg C.A., Human movement activity. Learning and execution in different situations [in Polish], Warszawa, 2009, p. 130.

2 Błaszczyk J.W., Clinical biomechanics. Handbook for students of medicine and physical therapy [in Polish], PZWL, Warszawa, 2004, p. 270.

3 Bober T., The biomechanics of walking and running [in Polish], *Studia i Monografie AWF we Wrocławiu*, 1985, no. 8.

4 Wiesner W., Postulates of technical formation and the process of learning sport technique, [in:]

for the assessment of locomotion in water, is based on the qualitative features of motion and is applied mainly in professional sports, i.e. swimming at high speed[5].

In acquiring swimming skills, the main goal aside from the speed of the motion in the water, is the manner in which the movement is executed, which will allow the learner to swim the desired distance. Thus, in the process of learning to swim, the overriding goal of movement is that it be carried out effectively[6].

The human movement development which takes place in ontogenesis is the result of the body maturing, as well as the individual's experience, which be can be called the process of learning. Ontogenesis is the process of individual development which occurs according to the stages defined for particular bodily functions. The changes which take place in ontogenetic development are the result of both learning and motor development, as they refer to both the psychological and motoring sphere of the human being; jointly known as the psychomotoring process. In the sensomotoring education process, the number of nerve connections in the brain increases, as do the connections between the system of reflexes and muscles. Awareness of the basic mechanisms of the psychomotoring development of the child allows for an evaluation of the child's motor activity and motor capabilities, in the following stages of life. This is why children whose movements are stimulated from birth possess developed kinaesthetic abilities.

Swimming belongs to a group of motion activities where the required skills can be learnt from the first months of the baby's life[7]. Motor activities in water, addressed to small children, aim to improving the vitality and acquisition of new motor skills. Many researchers emphasise that, in the case of the small child, movement is the main means of making contact with the environment, and serves as a tool for learning about the world[8].

This is why motion exercises, which stimulate the psychomotor development of the child are an essential educational element in the child's early development.

Thus, is seems justified that the biomechanical analysis of movement, supplemented with the theory of learning and the teaching of locomotion activities, can constitute a pattern in the process of teaching small children to swim.

The goal of this paper is to characterise the locomotion of a small child in water, based on measurements and an analysis of the biomechanical parameters of movement, and to draw conclusions for teaching purposes.

The following research hypotheses were adopted:

- Registration and analysis of small children's locomotion in water allows for an evaluation of their motor capabilities.
- The manner in which small children move in water is connected with their psychomotor development.

Czabański B. (ed.), III The School of biomechanical and technical teaching of sport [in Polish], *Zeszyty Naukowe AWF we Wrocławiu*, 1983, no. 34, p. 143.

5 Kornecki S., The biomechanical factors of effective task solution in water in the example of the butterfly [in Polish], *Rozprawy Naukowe AWF we Wrocławiu*, 1979, no. 14, pp. 7–44.

6 Czabański B., Psychomotor formation [in Polish], AWF, Wrocław, 2000, p. 126.

7 Konieczny G., Antoniak-Lewandowska K., Teaching babies swimming – fashion or necessity, [in:] Ring H., Soroker N. (eds.), 2nd World Congress of the International Society of Physical and Rehabilitation Medicine, ISPRM, Monduzzi Editore, Prague, 2003, pp. 457–460.

8 Osiński W., Anthropomotorics [in Polish], AWF, Poznań, 2004.

– Monitoring changes in the way a small child makes movements in the water, based on biomechanical measurement tools, will allow for the formulation of a methodical behaviour which could be used in the process of teaching small babies to swim.

METHODS

To date, the locomotion of babies in water has not been the subject of biomedical research because of the particular properties of the sample population, and due to the sophisticated and expensive research and measurement equipment. The research participants were healthy babies, who did not display any dysfunction of the nervous or locomotion system, which could impact their behaviour in water. The subjects of this analysis were children aged between 18 and 30 months, with a body weight of 12.4 (± 1.4) kilograms and a body height of 0.82 (± 0.05) meters. The children participated in the program of early motion stimulation in the water environment. The research had a continuous character and lasted 30 months. Thirty children were chosen for the biomechanical analysis, and they participated independently in water, in standardised inflatable sleeves. In order to identify the movement of particular lower limb segments, markers were placed on the following points: hip joint (hip X,Y), knee joint (knee X,Y), ankle (ankle-bone X,Y), heel (heel X,Y), toe (foot tip X,Y). The child was filmed during free locomotion in the water, where the child taking part in the research, swam through the filming area without physical contact with the guardian. The area of filming was marked by a reference system that was 1 meter wide, and was removed from the water after being registered on film. All measurements were made in the Indoor Swimming Pool of the University School of Physical Education in Wrocław, in a pool measuring 16 × 5 m and in water with a temperature of 34°C.

In 2007, The Ethics Commission of the University School of Physical Education in Wrocław gave its consent to conduct the research. All of the children's parents expressed their written consent for their child to participate in research conducted in the water.

The research method consisted of registering the motion of the child's lower limbs underneath the water's surface[9] (Fig. 1). A Sony digital camera in a waterproof casing was placed underwater on a stationary tripod, in such a way that the optical axis of the lens was placed perpendicular to the subject being filmed. In order to convert the distances of the image points to real-life dimensions, a calibration system was built from appropriately re-enforced plastic bars, to form a cube with the dimensions of 1 × 1 × 1 m. The image from the underwater camera was controlled in real time on a screen placed outside the swimming pool. The prototypical research equipment having the quality certification no. 1374-d/2/ 2009, PN – EN ISO 9001:2001.

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[9] Antoniak-Lewandowska K., Babies' and children's locomotion in water, [in:] Wolański W. (ed.), Biomechanics'06. International Conference, 6–8 IX 2006, Zakopane, *Zeszyty Naukowe Katedry Mechaniki Stosowanej Politechniki Śląskiej w Gliwicach*, 2006, no. 26, pp. 9–12.

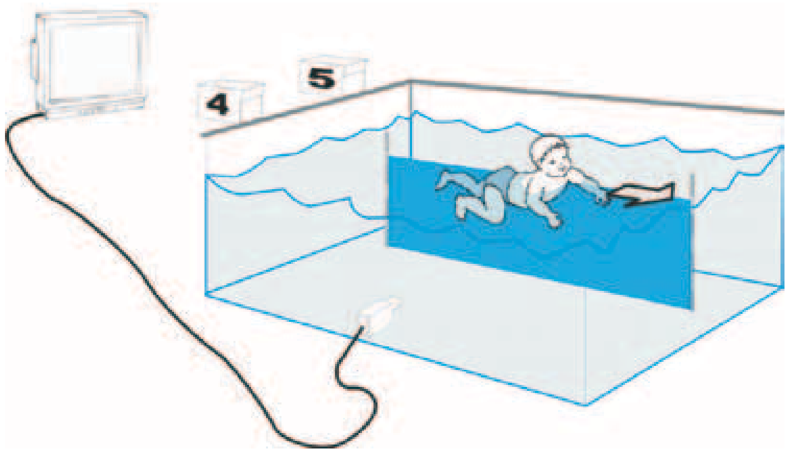

FIGURE 1. Arrangement of the film plan

To monitor the changes in the motion activities in the water, filming techniques and specialised software were used – including a SIMI Motion computer system of motion analysis – while the study of research material conducted by the Laboratory of Biomechanical Analyses of the University School of Physical Education in Wrocław, having the Quality System Certification no. 1374-b/2004, PN-EN ISO 9001:2001.

The computer system used in the research allowed for the measurement of kinematic parameters of motion and the visualisation of the conducted measurements. The data values obtained characterize the time intervals of an individual motion cycle. The SIMI Motion software enables the direct application of the data, as well as in future comparative studies. Based both on pilot studies, and the author's own experience, an assumption was applied to the research; that the alternate locomotive movements of a young child performed in the water consist of the bending and extension of the upper and lower limbs at the joints.

The application of the above assumption, as well as exclusion of video analysis of movement cycles which did not comply with the filming plane, allowed for the registration of movements using a single camera, which was set perpendicular to the direction of the child's movement in water.

RESULTS

The system of markers placed on the children's lower joints enabled the registration of the movement in time. The obtained research film material was submitted for computer analysis where the research procedure consisted of the following activities:

1. Determining the position of the markers.
2. Setting the angles for the following joints of the lower limb.
3. Division of the movement cycle (the cycle – minimal position of the toe to the next minimal position of the toe).

4. Cutting the sequence of angles into cycles.
5. Normalising the timing for cycles and for the sequence of angles.
6. Drawing average sequences of cycles for each child.
7. Determining the timing of cycles for every child.
8. Drawing average cycle times for every child.

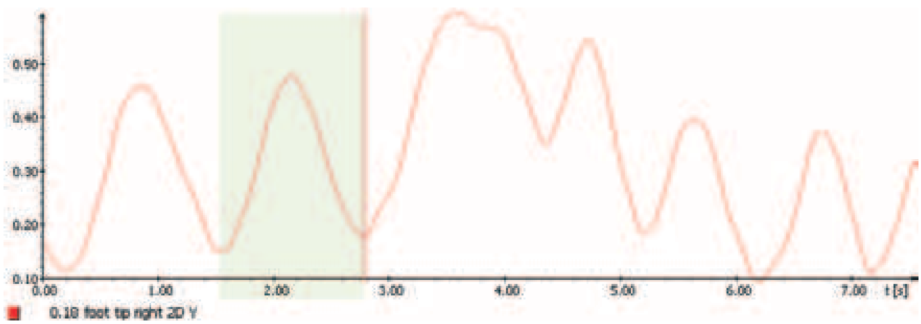

FIGURE 2. Dividing the motion into cycles (self developed)

The specificity of the body's motion relies on the fact that it is impossible to repeat both the movement duration and maintain a stable value of the angle of the given joint. The values obtained during the biomechanical measurements, both data in figures and in graphs, are characterised by a great variability. This results in the necessity to convert the original time scale (for example expressed in seconds) to a "percentage duration cycle" within a range from 0 to 100%. The procedure described above is called normalisation.

There were 10–13 movement cycles registered for every child in the conducted research (Fig. 2). Thus, in order to make comparative characteristics of the movement cycle of the studied children, the normalisation of the angle values for the lower limb joints was performed. The conducted procedures are displayed in Fig. 3 and 4.

The purpose of the research procedures was, to indicate to what degree the analysed values are of a prognostic character, and then, if they can be a target criterion for the evaluation of the techniques in the process of learning to swim. The assumption was made that a parameter which describes movement and value, but which does not change, in the ontogenetic process, is the angle value. In such procedures there is a correlation, or a biomechanically functional relationship, between the parameter describing the movement, known as the angle value, and the target value, i.e. the distance, which is called "the deterministic model of the qualitative analysis"[10]. In this model the parameter describing the movement is the value impacting on the locomotion result, and enabling the quantitative characteristics of the movement. The assumption was made that, in the age group studied the most indicative parameter is the angle value of the hip joint.

[10] Król H., Criteria of selection and evaluation of exercises perfecting the sports technique [in Polish], AWF, Katowice, 2003.

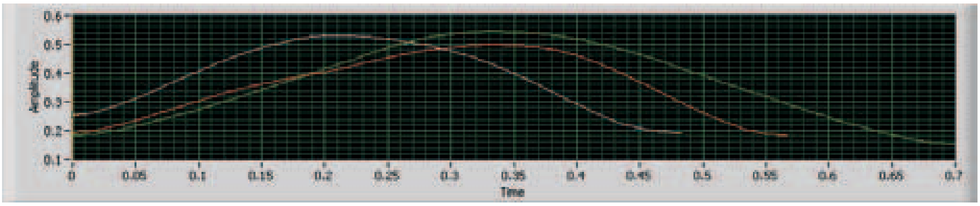

FIGURE 3. An example of the recorded angle values in the hip joint before normalisation

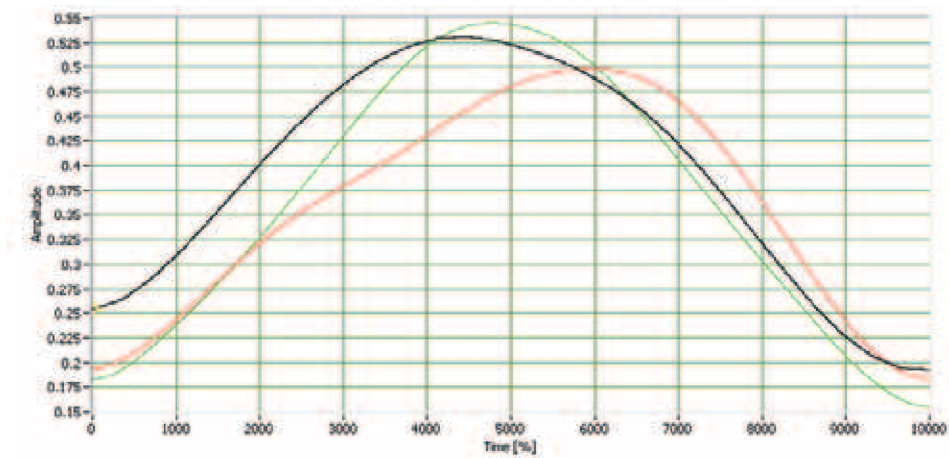

FIGURE 4. An example of the recorded angle values in the hip joint after normalisation

As a result, a statistical analysis was conducted with the purpose of displaying the impact of the biomechanical parameter, which was the angle value in the hip joint, correlated to the target value i.e. the distance[11] (Tab. 1).

TABLE 1. The results of the statistical breakdown for the angle value in the hip joint

Average	Standard deviation	Maximum	Maximum time	Minimum	Minimum time	Range	Number of samples
141.46	21.02	172.96	0.60	107.30	1.03	65.65	71.18

The presented research procedures allow for the use of biomechanical tools to monitor the process of teaching swimming skills at various stages of ontogenetic development. The observation of the locomotion movements of small children in water allows for the supposition that; the research assumption that the registration and biomechanical analysis will lead to the deciphering of the locomotion pattern of a small child in water. This pattern can in turn be used in both monitoring the learning process, or rehabilitation during a given level of ontogenetic development. The characteristics of the locomotion movements of small children in water seem to constitute an original contribution to the characteristics of hu-

11 Ryguła I., Research process in sports sciences [in Polish], AWF, Katowice, 2004.

man locomotion in water[12]. Until now, young children have not been the subject of biomechanical research mainly due to the specific features of the sample population, as well as the sophisticated and expensive nature of research and measuring equipment. The conducted research procedures allowed for a demonstration of the degree to which the analyzed values have a prognostic character, and thus can constitute a criterion for technique evaluation. The angle values chosen for the characteristics of the young children's locomotion in water seem to be justified, as they are not subject to changes in ontogenesis and they can be used to monitor changes in the values of the kinematic parameters. The research to date shows that, a biomechanical analysis of the kinematic locomotion parameters of small children should follow a correlation between the angle values in particular joints of the lower limb, and the X or Y component of the lower limb.

From a hydrological point of view, the locomotion effect of humans in water is the compilation of a forward movement, which is the body locomotion, and a circular movement, which is the movement of the upper and lower limbs. In the case of the small child, the lower limbs constitute the main propelling mechanism during water locomotion. In the conducted research, a hypothetical assumption was made, that there are specific and common locomotion patters for a given age and psychomotoring development, which could constitute the synthesis of the locomotion process for the given motor activity. This is why an analysis of the timelines of movement should concern, not so much an increase in the value of the numbers, but the repetitions over time. The biomechanical characteristics of the movement provides information about the degree of organisation and the position of the body parts in the given motion phases, which for a young child is the stretching and concluding movements. The fluidity of movement is the manifestation of locomotion, which is characterized by the development changes occurring in ontogenesis, and in the progress of acquiring motor activities[13]. An analysis of the structure of the lower limb movements points to a relatively high degree (reaching 90° angle in the hip joint) which reflects the level of the small child's motor development. Any structure of the child's lower limb movement cycle is not fundamentally different from the manner in which other individuals make the alternate side movement with their lower limbs; the only principal difference being the angle value of the hip joint. The analysis of graphs showing the course of line movements of the child's lower limb, indicates a record of repetitiveness, and that the transitions between the phases are fluid, as is documented by the time intervals. The tracks of the respective points on the limb, on the Cartesian axes, can be treated as geometrical patterns of movement and constitute a benchmark of progress in swimming acquisition and the rehabilitation of the locomotion system of babies and small children. Because swimming is made up of cyclical movements, the occurrence of phases and their fluid sequence proves the accuracy of the movement. The observation of the locomotion movements of small children in the water allows for the scientific supposition that; registration and biomechanical analysis is a point of departure for preparing the parametric pattern of

[12] Maglischo E.W., The basic propulsive sweep in competitive swimming, [in:] Morrison W.E. (ed.), VIIth International Symposium of Biomechanics in Sports, Footscray, Melbourne, 1989.
[13] Czabański, op. cit.

a child's motor behaviour in water. This pattern could in turn be used to monitor the course of swimming acquisition and rehabilitation in water, at a given stage of ontogenetic development. The application of these patterns in practice requires their experimental and biomechanical verification on a larger sample, taking into consideration the acquisition theory and the teaching of motor activities in water.

Characteristics of the participants' propulsion movements in water are an original contribution to characterising human propulsion in water. So far, small children have not been the object of biomechanical research, mainly due to the particular characteristics of sample populations, as well as the sophisticated and expensive nature of measurement and research equipment. The procedure of the research conducted, revealed the extent to which the analyzed volumes have a character suitable for forecasting, and therefore whether they can provide criteria for evaluating the technique. The value of the angle that has been chosen for the characteristic of the participant's locomotion in water seem to be justified, because they are not subject to a change in ontogeny and can be used to monitor changes in kinematic parameters. Previous studies have shown that, a biomechanical analysis of the kinematic parameters of movement for young children, should be heading in the direction of relationship between the changes of the angle value in individual joints of the lower limbs, and the length of the distance swum by a child in a single motor cycle[14].

CONCLUSIONS

The essence of a child's locomotion in the water is not the development of speed, but mainly the generation of power in order to remain on the surface. A child may temporarily remain on the water's surface, but cannot move independently. Therefore, in teaching young children movements that allow for locomotion in water, it is typical for inflatable sleeves, also known as "wings", to be used[15]. This "wings" allow the child to breathe easily and move in the water independently, without physical contact with an adult.

Using inflatable sleeves causes some restrictions to the movement of the upper limbs', which are an additional driving element in human aquatic locomotion. In the situation when the movements of the upper limbs is largely limited, the main propelling force making the locomotion possible becomes the child's lower limbs. Research, based on biomechanical analysis of motor activities in water, as well as experience as a swimming teacher, allowed me to adopt the assumption that a young child achieves a locomotion effect in the water mainly through the movements of bending and stretching the joints of the lower limbs, while the condition of gaining the locomotion effect maintains the continuity of movement. Movements which are performed at regular or almost regular intervals are described as smoothness. Movement fluidity is the manifestation of the locomotive force, characterised by changes occurring in ontogenesis, and in the process of learning

14 Antoniak-Lewandowska, op. cit., pp. 9–12.

15 Cesari J., Teaching infant and preschool aquatics water, Experiences the Australia Way, Human Kinetics, Autswim, 2001.

motion activities[16]. Fluidity of movement is very often used as the main criterion of the motion evaluation since well mastered motion is always fluid. In the fluid motion, time intervals are maintained and there is a constant sequence of movements; called an algorithm of motion, proper for the given motion activity. Breaks in the motion, i.e. "stillness" have an impact not only on the aesthetics of the motion, but mainly on its effectiveness. The objective evaluation of the means to execute the locomotion task in water, should be based on quantitative indicators such as: the technique, speed, acceleration or changes in the angle value describing the motion and its scope.

From the hydrodynamic point of view, the locomotive effect of humans in water is the result of an interaction between human movement mechanisms and a reaction of the aquatic environment[17]. During the locomotion of a young child in the water, the legs are the main driving mechanism.

In conclusion, we can assume that as a result of the biomechanical verification, taking into consideration the acquisition of motor activities and teaching theories, the tracks of respective points on the lower limbs in the Cartesian axes, can be treated as geometrical patterns of movement. They can also be a benchmark of progress in the process of swimming acquisition and rehabilitation of motor system dysfunction of young children.

A biomechanical analysis of the young child's course of movement in water indicates a relationship between the changes of the lower limb angle value and the duration of their occurrence in the motor cycle. The classification of water locomotion based on measurements and a kinematic parameter analysis, is a new opening in the research into human propulsion in water – at the stage of movement identification[18].

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[16] Czabański, op. cit.

[17] Maglischo, op. cit.

[18] Haljand R., Swimming Technique Analyses. Swimming/Notation Canada Prepared by the National Swimming Sport Science Centre, Calgary Practical Coaching Handbook of the Biomechanics of Swimming, 2006.

≋ SCIENCE IN SWIMMING III, 2011, 31–39

Relation between values awareness and effectiveness of learning front crawl swimming technique

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INTRODUCTION

Education is a continuous, multilateral process consisting of creating a spiritual and material reality, which takes place not only in present times, but which are also directed at problems of the future. It belongs to the sphere of human reality which helps to prepare for decent existence in the world. Education helps young people step into adult, independent life. As the world of man is also a world of culture, it also prepares for participation in the cultural life and multiple culture achievements. It has to present various worlds of values to prepare pupils to independently choose different strategies and lifestyles. Until not long ago, the raising and educating of young generations was based on teaching how to participate in the culture of work, whereas today the goals are self-education and self-improvement. It seems that in the future, one of the most important tasks of education, will be preparation for the spend of leisure time in an active way[1].

Thus, the task of education is to develop universal values such as: truth, good, and beauty, as well as dignity, responsibility, justice, freedom, subjectivity and personal identity. Education should facilitate the recognition of reality as a complex of values which should be competently learned, redefined and internalised so that they could be useful in shaping the reality and development of the people themselves[2].

The method of teaching certain school subjects is vital in the process of leading a student into the world of values. And it is important, not only during theoretical lessons, but also in physical education classes. A student, while perfecting or learning new skills, develops internally and becomes a new person. Once discovered, those abilities give a chance to perceive oneself, and the surrounding world in a new and different light[3]. Methodology of handling (carrying out) a sport lesson should prepare a student to participate in a physical culture understood as be "the whole of values, well established behaviours and outcomes referring to the

1 Grabowski H., What do Physical Education and Education have in common? [in Polish], *Wychowanie Fizyczne i Zdrowotne*, 2001, no. 2, pp. 4–8; Kobylarek A., Education in the context of global and civilisational transformations [in Polish], *Kultura i Edukacja*, 2001, no. 2, pp. 7–21.
2 Banach C., Values in the Educational System [in Polish], *Lider*, 2001, no. 3, pp. 3–5.
3 Juszkiewicz M., Swimming as a lifelong movement activity proposal, [in:] Umiastowska D. (ed.), Movement activity in people of various ages [in Polish], Albatros, Szczecin, 2005, pp. 302–308.

human body"[4]. Therefore, while leading a lesson of light athletics, gymnastics, team games or swimming; and while teaching a certain movement activity, the teacher should make students aware of the skill's functions and roles it may play in the future[5]. Only actions supporting internalisation of the proposed values can contribute to their permanent inclusion in one's individual sphere of human values and lead to life in harmony with those ideals[6].

Swimming can by analysed in an axiological context and is this kind of sport which people may do throughout their entire life. One can participate in this form of physical activity for the major part of their life. Since swimming is a safe discipline (fairly small number of injuries), it is frequently recommended to the elderly or during medical rehabilitation. Most other sport disciplines, like team games or martial arts, do not possess such advantages. There are also numerous disciplines, which because of high difficulty or strain for the body, have a marginal offer to society. Taking up skating or sailing requires both time and financial investment. One needs to dedicate a lot of time in order to become a licensed sailor or spend a lot of money to provide specialist skating equipment. In recreational swimming, on the other hand, costly, specialist equipment is unnecessary. Additionally, not all sport disciplines grant such a wide range of choice of certain instrumental values. Swimming is highly valued and often preferred form of physical activity. It belongs to this group of disciplines where, having mastered the technique, one can choose among following possibilities: vital, recreational, hedonistic, etc. – focusing on further development. While analysing reasons why certain forms of movement activity are more popular than another, we may come to the conclusion that their appeal relates to a sense of gravity of the values which are intuitively sensed, or intellectually discovered and internalised, in certain kinds of sport activities[7]. Thus, becoming aware of the values evoked by human movement activity, in water allows not only for more conscious participation in this form of activity, but also makes both teaching and learning to swim easier. Intellectual and emotional discovering values connected with movement activity in water is expressed by motivation to take up swimming[8].

The aim of the present research was to explain the experimental connection between information about the meaning of the skill of swimming, and its importance for realisation of different types of movement behaviour connected with water and accepted by a student as well as effectiveness of learning the front crawl technique.

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4 Grabowski H., What absolutely needs to be known about Physical Education [in Polish], Impuls, Kraków, 2000, p. 30.

5 Pawłucki A., Body Value Pedagogy [in Polish], AWF, Gdańsk, 1996, pp. 57–89; Wiesner W., Teaching – learning how to swim [in Polish], AWF, Wrocław, 1999.

6 Juszkiewicz M., Human as a physically active being, [in:] Dziubiński Z. (ed.), Anthropology of sport [in Polish], Salezjańska Organizacja Sportowa, Warszawa, 2002, pp. 88–97.

7 Juszkiewicz, Swimming…

8 Ibid.

METHODOLOGY

The research was carried out in 2005/2006 school year. The study participants included 9-year old 3rd-grade students of Wrocław primary schools. Selected students started learning to swim in their second school grade. The idea behind such a method of selection was that the information about values resulting from the skill of swimming could be effectively passed on to the oldest students in the early-education period. It was essential that children participating in the experiment fully understood and consciously received knowledge about the values resulting from the skill of swimming.

Swimming lessons were compulsory for primary school 3rd graders. The 45 minute lessons took place once a week, carried out in a 25 metre swimming pool with water temperature favourable for swimming training. The groups were co-educational. All chosen swimming pools met legal and methodological conditions and requirements. Each swimming pool had a lifeguard on duty and was equipped with didactic aids. Somatic, motor and intellectual differences between 9-year old boys and girls are not vitally important in physical education didactics[9]. Therefore, it was possible to handle lessons in co-educational groups.

The population of children attending three Wrocław primary schools amounted to 194 students – before selection for the research was started. The main factor qualifying for the experiment was their starting swimming skills established in initial examination.

In order to determine the above, children were tested in four exercises:

- underwater exhale (with head fully submerged);
- front glide after kick off from the pool wall;
- back glide after kick off from the pool wall;
- pencil water entry jump.

For each trial a student received from 0 to 2 points. Each attempt should was to be awarded at least 1 point which gives minimal result of 4 points in the whole test.

Additionally, the students' ability to a swim breaststroke was examined in order to exclude those who had already learned to swim outside the school. All children who were able to demonstrate front crawl technique or performed any types of movement resembling this technique were moved to groups not subjected to the experiment. Also children unaccustomed to water were not included in the experiment. The process of learning a new skill may evoke various emotions, and fear of water could disrupt the final results of the experiment.

After running the pilot check, 152 pupils were qualified to the further stage of the experiment, which included Raven Matrices Test and an individual buoyancy test. Undoubtedly, the intelligence level of a junior pupil has a considerable influence on the child's emotional, cognitive and psychomotor sphere.

It can even be perceived as the causative factor for speed and effectiveness of gaining knowledge as well as its retention. The individual level of the examined

[9] Wolański N., Human biological development [in Polish], PWN, Warszawa, 1977; Ignasiak Z., Morphological and motor features factors in young school-age children in the light of diverse biological age [in Polish], *Studia i Monografie AWF we Wrocławiu*, 1988, no. 19.

pupils' buoyancy may also have an impact on how quickly they master front crawl stroke technique. Human buoyancy (understood as lean body mass, body fat and the air in the lungs, that affect a swimmer's flotation in water) along with general physical fitness, motor abilities and suitable body build is one of the most important factor determining natural predispositions to engage in swimming[10]. Numerous authors (Czabański, Fiłon, Zatoń) agree that in equal conditions swimmers with better buoyancy master stroke technique faster, with lower energy loss and stand out with better effectiveness. Thanks to better buoyancy, a swimmer does not waste energy to overcome gravitational forces and thereby can use it to develop propulsion force[11].

Having carried out all pilot trials, the researchers qualified children demonstrating similar swimming abilities, the level of intelligence and similar body buoyancy to subsequent stages of the experiment. Pupils significantly different joined separate groups. Finally, 113 children took part in the experiment. The whole group was randomly divided into a control group (56 subjects) and experimental one (57 subjects).

Each lesson in the experimental group was preceded with 5 minute presentation of the materials described below.

Length of lessons was the same in both groups.

The following values, resulting from the skill of swimming were presented to the one by one:

- utilitarian, connected with the skill of optimal relocation in water for personal reasons as well as lifeguarding;
- recreational, understood as a form of spending one's free time, e.g.: kayaking, sailing or diving;
- health centred, where water is used to improve fitness of motor organs and nother body systems;
- hedonistic, understood as a joy of spending time in water;
- agonistic, based on covering the longest distance in the shortest time; e.g.: swimming competitions, or swimming marathons;
- esthetical as synchronised swimming, diving, or an athletic frame;
- social, based on contact with teachers and peers.

An example of the widely described contents presented to children may be work of a lifeguard whose main task is to watch over human life and to provide help to those whose life or health are endangered. The most important threats to health or life which occur while swimming are: drowning, choking, hypothermia, thermal shock, mechanical injury, wounds, cuts, exhaustion and weakness[12].

As it has been mentioned, motor skills applied in water lifeguarding contain great axiological potential resulting from the capability of save human life. The

[10] Bartkowiak E., Sport swimming [in Polish], COS, Warszawa, 1999; Strelau J. (ed.), Psychology [in Polish], vol. 1 i 2, GWP, Gdańsk, 2000.

[11] Fiłon M., Buoyancy in women and men based on body density research with the densitometric method [in Polish], *Kultura Fizyczna*, 1972, no. 10, pp. 439–441; Czabański B., Fiłon M., Zatoń K., Elements of swimming theory [in Polish], AWF, Wrocław, 2003.

[12] Wiesner W., Skalski D., Methodological bases of lifeguard education [in Polish], Julita, Skarszewy–Wrocław, 2003.

following values emerge during a water rescue action: responsibility, self-reliance, help and care devoted to the other person, while risking the lifeguard's own life, sensitivity and respect for other human beings. Water rescue equipment used in the water, as well as films showing motor and fitness preparation and lifeguard competition were presented during the talk on lifeguarding.

Those values were briefly presented before the first lesson beginning the process of teaching front crawl technique.

The experimental research was carried out by six physical education teachers, licensed swimming trainers or instructors. Their average teaching experience was 4–15 years and each of them had a master's degree in physical education. The same teacher held lessons in both the control and experimental groups without being informed about the main aim of the experiment, in order to avoid the subconscious influence of the teacher on its final result.

The subject and aim of the teaching programme, prepared especially for the sake of the experiment, were the same for both groups. The research took 8 weeks, one school-lesson per week. Altogether, eight lessons were carried out, with the same aims and subjects in both groups. After first lesson the pupil was to swim 15 metres, kicking off the wall and performing alternating front crawl leg kick. After the second lesson, the pupil was to perform the same task swimming 25 metres. During the third lesson, continuous alternating arm action, was introduced. After the fourth lesson, the pupil should be able to swim 15 metres performing front crawl leg and arm alternating action, while after the fifth lesson – the distance should rise to 25 metres. During the following lessons the swimmers focused on breath regulation over the same distance. After each of the 8 lessons teachers assessed whether the appointed aims had been achieved. Having participated in all classes, students should have achieved the main aim of the teaching process – mastering the front crawl swimming technique.

Motor effects were also evaluated in both groups after realising identical tasks. Before water entry, children got to know the aim of every lesson. At its end they found out how well the appointed aim had been achieved. Achieving lesson aims was scored in the 0–1 system. 1 point was granted for achieving the aim, 0 points – for not achieving it.

Aside from the obtained effects of separate lessons, also effectiveness of the whole teaching–learning process was also evaluated in the later period of time[13]. The front crawl swimming technique demonstrated by children was filmed and next assessed by independent experts – academics from the swimming research unit and swimming trainers with a minimum second class instructor's qualification. Their task was to assess front crawl technique at the standard level. The following points scale had been implemented:

5 pts. – very good A
4 pts. – good B
3 pts. – pass mark C
2 pts. – sufficient mark D
1 pt. – poor mark E.

[13] Zatoń K., Verbal communication during Physical Education classes [in Polish], *Studia i Monografie AWF we Wrocławiu*, 1995, no. 48.

Pupils receiving poor mark E demonstrated lack of skills and very poor front crawl swimming technique.

An average score received on the basis of separate opinions was used in results analysis. Each expert assessed each student separately and subsequently – gave the swimmer his mark. All marks were added up and the sum was divided by the number of examined pupils participating in the experiment. As a result of applying the above method of assessment, it was possible to avoid even subconscious (engagement and subjectivism) distortion of the research results by the experimenter. Thus, independently of the results of separate lessons, the whole effectiveness of the teaching–learning process was assessed[14].

RESULTS

The collected research results became subject to statistical analysis. It was directed at checking the effectiveness of the whole teaching–learning process at the end of the experiment and consequently, front crawl swimming technique at the standard level. The final mark of swimming technique was correlated with the number of operational aims achieved where: the more aims achieved – the higher technique evaluation.

Subjects accomplishing higher number of lesson aims received better mark for the front crawl swimming technique. 11 students got the maximum ("very good") score realising on average 7.7 of the lesson aims (Tab. 1).

TABLE 1. Results of swimming technique evaluation and number of achieved aims in separate lessons in both groups (N = 113)

Scoring	Mark	N	Average number of achieved aims
1	Poor	14	5.1
2	Sufficient	32	6.1
3	Pass mark	34	6.3
4	Good	22	7.1
5	Very good	11	7.7

TABLE 2. Experimental and control group swimming skills test presented in percentage terms and value of differences significance quantifying teaching effects

		Experimental Group		Control Group	
Scoring	Mark	N	%	N	%
1	Poor	1	2	13	23
2	Sufficient	9	16	23	41
3	Pass mark	20	35	14	25
4	Good	17	30	5	9
5	Very good	10	18	1	2

$\chi^2 = 31.37$; $p < 0.001$

[14] Ibid.

It is also significant to compare evaluation results of the front crawl swimming technique carried out in both: the experimental and control group. Test outcomes are presented in Tab. 2.

A higher percentage of high scores for the swimming technique can be observed in the experimental group. Fig. 1 presents visible difference between both groups ($\chi^2 = 31.37$).

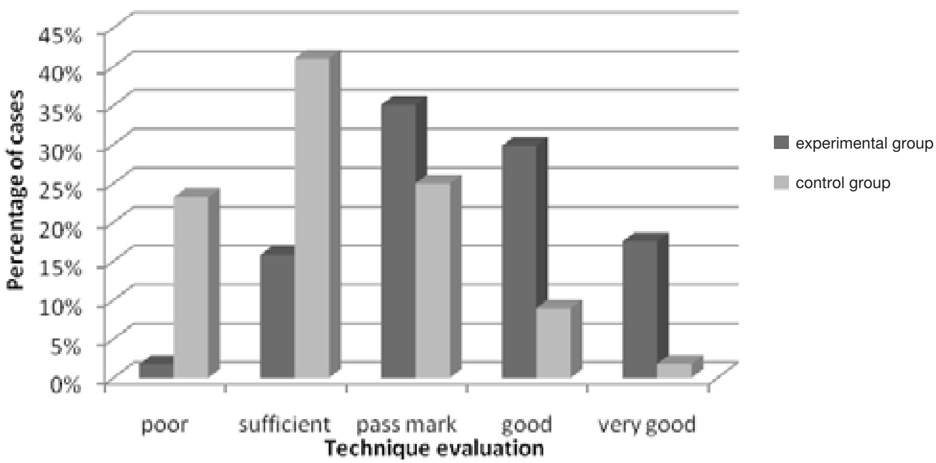

FIGURE 1. Front crawl swimming technique evaluation in experimental and control group

Within the experimental group, 2% of pupils received poor mark, while in the control group – 23%. Sufficient and pass marks were noted in turn for 41% and 25% of students in the control group. Additionally, 9% of students in this group were marked good and 2% very good.

Quite a different situation was observed in the experimental group where a sufficient mark was received by 16% of swimmers, and a pass mark by 35%. While 30% of swimmers were marked good and 18% very good.

Evaluation results of the front crawl swimming technique were also compared in terms of boys and girls groups (Tab. 3).

TABLE 3. Front crawl swimming technique evaluation in groups of boys and girls in the final teaching effect

		Girls		Boys	
Mark	Scoring	N	%	N	%
Poor	1	1	5	0	0
Sufficient	2	4	19	5	14
Pass mark	3	6	29	14	39
Good	4	7	33	10	28
Very good	5	3	14	7	19

Swimming technique test in extreme marks (poor and very good) appeared better in the group of boys.

The collected data were analysed by means of Spearman's rank correlation coefficient – used often to measure statistical dependencies between two variables, especially when analysed qualities are expressed in an ordinal scale.

TABLE 4. Correlation of the number of achieved aims with final swimming technique mark in both groups

Correlation	Experimental group			Control group		
	Correlation coefficient	T	p	Correlation coefficient	T	p
Swimming technique	**0.29**	2.22	0.030	0.16	1.20	0.234

Correlation with final swimming technique level is low (however statistically significant) in the experimental group. In the control group – correlation is statistically insignificant (Tab. 4).

DISCUSSION AND RESULTS

Research described in the present study aspired to determine the influence of information about values resulting from the skill of swimming passed on to students before swimming lessons and on the effectiveness of teaching–learning process of the front crawl swimming technique. At least two premises introduced by Denek[15] justify the need to explore this area of the teaching–learning process. The first one is civilisation crisis and consequently: a crisis of humanity. The crisis of values did not circumvent pedagogy either. The only way to break the stalemate and fix common civilisation is by bringing back meaning to values. "Values are a key problem in school education"[16]. The faster pace of civilisation's transformations, the more attention should be paid to well organised education systems created on the foundation of values[17]. They outline directions of actions chosen by both teachers and students. They are a source of inspiration and tendencies in education. Finally, they determine choices and decisions, therefore it is necessary to introduce axiological education as being a priority in today's world[18].

Until now, the problem of values has been presented in scientific works only theoretically. However, no research confirming their analyses has been carried out. Thus, the purpose of the present study was to validate the theory experimentally. The results of the research reveal clearly that in the experimental group, where aquatic values had been presented, the effectiveness of teaching–learning process was higher than in the control group. In the experimental group 30% of

15 Denek K., Axiological aspects of school education [in Polish], A. Marszałek, Toruń, 1999.
16 Ibid., p. 31.
17 Semków J., World of values as a neccessary point of reference foe a learning person [in Polish], *Kultura i Edukacja*, 2000, no. 3–4, pp. 97–103.
18 Denek, op. cit., pp. 30–33.

students swimming front crawl at the standard level received B mark and 18% received an A mark. In the control group only 9% of students were marked B and not more than 2% – A. Such good results in the experimental group cannot be explained by the children's better buoyancy. Better buoyancy is a factor in improving effectiveness of teaching and the level of mastering swimming technique. This is quite an obvious conclusion. It is also very well visible in 10-year old children are introduced to the front crawl technique at the standard level. Better buoyancy facilitates, learning of swimming technique and improves breathing conditions. 10-year old children, who were the subjects of the research, did not have a sufficient amount of physical strength and stamina necessary to master swimming technique more quickly. They could however, compensate for those deficiencies with a higher level of buoyancy. Yet, it must be remembered that thanks to the applied method of dividing the subjects into groups, the buoyancy level in both of them did not differ significantly. Thus, both experimental and control groups were homogenous.

Intentional transfer of knowledge about values causes a higher percentage of students to realised the significance of aquatic values. Additionally, motivational quality of values is also present in the process.

The size of the research group and the research results do not form the basis for generalisations and drawing categorical conclusions. Nonetheless, the experiment points out a certain regularity. One may conclude that intentional transfer of knowledge about values resulting from the skill of swimming brings about a higher level of learning front crawl swimming technique.

≈ SCIENCE IN SWIMMING III, 2011, 40–47

Word – Image – Information

The effectiveness of teacher behaviour during swimming lessons

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INTRODUCTION

The school system typically follows the paradigm of educating the student towards freedom, responsibility and autonomy while retaining the tolerance towards dissimilarity of beliefs, constructing multithread, complex situations and teaching the ability of interpret and understand them[1]. However, it is still contradicted by biased methods and means of teaching, which do not force the student to face the real world, but only equip them with the knowledge (treated as a collection of information) which must be presented when questioned. It seems that it would be much more efficient (instead of simply demanding knowledge); to teach its transformation, interpretation and noticing its ambiguity. This in turn would show the student a manner of gaining information and its shared relationships, and would allow the individual to move freely in modern life.

In the field of physical education, the biggest concern for the teacher is the manner in which to efficiently and effectively prepare the student for a life in a world of knowledge, information and media. Despite the observed overload in young people's education, with all contemporary forms of information technology, the teacher is still the one who steers, leads and modifies the process of student education and knowledge acquisition. Obtaining information, for example on the Internet, is not equal with gaining knowledge. The role of the teacher is to direct the student to the proper technique of analysing, separating and memorizing the information.

If information is to be treated as an element of the communication process and if this element of the process is to be treated as "the connective point of the human mind or, if you wish, the human brains"[2], then information is the union of

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1 Ogonowska A., Education through the Media. A Key to Understand Social Reality [in Polish], TN Societas Vistulana, Kraków, 2003.

2 Baylon Ch., Mignot X., Communication [in Polish], FLAIR, Kraków, 2008, p. 18.

the means of delivery, structure and semantics[3]. Yet it gains an interactive character which is disposed to feedback coming from the recipient[4]. The learning environment is an area of constant interaction between the teacher and the student. Information flowing both ways; from the teacher to the student and from the student to the teacher, may become a double-subjective plane of communication activity.

Speech is the dominating and best available signalling channel for regulating human behaviour. We talk about "the verbalization of all human psychological processes"[5]. Włodarski[6] claims that word connections are the only characteristic human learning. They are the basic and leading forms (apart from sensual representation) in human learning and experiencing. Basic in the sense that everything a person learns is of a verbal form. It supports acquiring, processing and adding information to the knowledge resources of the individual. The knowledge, of which, is also expressed verbally.

Visual perception is considered to be an especially important sense due to the amount of information humans receive with the use of their sight analyzer. These are mainly perception data which is stored in the iconic memory. In his experiments, Richaudeau states that visual memory is the most effective form for a short and long term memory. Many researchers show the superiority of images over words[7]. It starts with the process of perception, the creation of the perception in the mind, the representation of shape and reproduction, all the way to the process of remembering and information recreation. Jagodzińska[8] states that the inability to remember images is a slower process than forgetting verbal information. Three types of coding: visual-spatial, verbal-sequential and abstract-hypothetical were distinguished[9]. These include the possibility of information flow in one code, e.g. visual or verbal, while the second is supplemented by the recipient or when the impulse is coded and is similarly received in both codes. It allows for the transfer of information from one code to the other.

Simultaneous use of verbal and visual methods is called the 'audio-visual effect', which is possible due to the above mentioned duality of human perception[10].

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3 Kurcz I., Memory. Learing. Language [in Polish], Wydawnictwo Naukowe PWN, Warszawa, 1992.

4 Dylak S., Visualization in Teachers Education [in Polish], UAM, Poznań, 1995.

5 Łubowski W.I., A Word and a Child. The Development of the Verbal Regulation of Behaviour in Children [in Polish], WSiP, Warszawa, 1983; Sztejnberg A., The Basis of Social Communication in Education [in Polish], Astrum, Wrocław, 2002.

6 Włodarski Z., Receiving the Content in the Process of Learning [in Polish], PWN, Warszawa, 1985.

7 Dylak, op. cit.; Jagodzińska M., Image in the process of learing and acuiring. Information, Operation and Mnemic Specification [in Polish], WSiP, Warszawa, 1991; Nowak A., The Film Programmed as one of the Control Forms of Learning During Physical Education Lessons, [in:] Bartoszewicz R., Koszczyc T., Nowak A. (eds.), Control and Evaluation in Physical Education [in Polish], WTN, Wrocław, 2003, pp. 173–179; Clark J.M., Paivio A., Dual coding theory and education, *Educational Psychology Review*, 1991, vol. 3, no. 3, pp. 149–170.

8 Jagodzińska M., The Memory of Images [in Polish], *Psychologia Wychowawcza*, 1988, no. 2, pp. 142–156.

9 Anderson J., Learning and Memory. An Integrated Approach [in Polish], WSiP, Warszawa, 1998.

10 Włodarski, op. cit.

In order to convey the information during motor skills education, teachers use a method based on the words, observation and practical actions of the students. However, as the literature shows, the first two are the dominant[11].

Important studies of the verbal transmission used in the teaching–learning of motor skills, although in a different perspective, were presented by Bukowiec, Kübler, Mazur, Srokosz, Wiesner and Zatoń. Their research proved that verbal transmission used during physical education lessons comprises of 50–63% of the lesson. Experimental research done by Zatoń, who analyzed the structure and the content of verbal transmission, showed that the improvement of the didactic process depends not on the amount of verbal information, but mainly on its verification according to the semantic, syntactic and pragmatic criteria[12].

Syntactic criterion allows for the course of a motor skill to be assigned according to its separated and ordered sensomotoric sequences (the algorithm of movement changes in the student's joints). The semantic criterion refers to the definitions used by the teacher. An indication of the pragmatic criterion is the possibility of the transformation and accomplishment of the content conveyed to the student[13].

Wiesner's research results[14] reveal a very high level of verbal activity from the teacher; exceeding 25% of all the actions undertaken by the teacher during the lesson. Such a characteristic is typical for teachers with a lower seniority. Wiesner says that excessive verbalization is the result of the teacher's functional imperfection, and this leads to a limitation in the student's perception, because the verbalization of the teaching process in physical education, should mean the higher efficiency of the verbal transmission, and not an increase in loquacity. Spackman[15] claims that 67.2% of a physical education lesson is devoted to active teaching. In Hardy's[16] research it is 78.4%. Biro[17] observed the swimming lessons during

[11] Zatoń K., Significance of verbal information in the process of teaching and learning motor skills, [in:] Błachnio A., Drzewowski M. (eds.), Communicative Interactions in Education from the Perspective of Situational and Contextual Meanings [in Polish], A. Marszałek, Toruń, 2008, pp. 407–416; Nawrocka W., The analysis of the combination of demonstration and verbal perspective of movement as the basic didactic methods used in the process of physical education [in Polish], *Wychowanie Fizyczne i Sport*, 1960, vol. 4, no. 1, pp. 91–102; Czabański B., Psychomotor Education [in Polish], AWF, Wrocław, 2000; Coh M., Jovanovic-Golubovic D., Bratic M., Motor Learning in Sport, *Facta Universitatis. Physical Education and Sport*, 2004, vol. 2, no. 1, pp. 45–59.

[12] Zatoń K., The Effectiveness of Verbal Information in the Process of Motor Education in Swimming [in Polish], *Rozprawy Naukowe AWF we Wrocławiu*, 1985, vol. 16, pp. 218–282; Zatoń K., Verbal communication during Physical Education classes [in Polish], *Studia i Monografie AWF we Wrocławiu*, 1995, no. 48.

[13] Czabański B., Fiłon M., Zatoń K., Elements of Swimming Theory [in Polish], AWF, Wrocław, 2003; Czabański B., Motor Skills Education [in Polish], AWF, Wrocław, 1998.

[14] Wiesner W., Didactic communication and the level of teachers' authoritarianism [in Polish], *Studia i Monografie AWF we Wrocławiu*, 2005, no. 76.

[15] Spackman L., The systematic observation of teacher behavior in physical education. The design of fan instrument. Thesis, University of Technology, Loughborough, 1986.

[16] Hardy C.A., Teaching behaviors of physical education specialists, *Physical Education Review*, 1993, no. 16, pp. 19–26.

[17] Biro M., Survey of different types of communication in swimming education, *Physical Education and Sport*, 2007, vol. 51, no. 1, pp. 5–8.

which 12% of the instruction time was used for verbal transmission and 6% for visual. At the same time, Biro acknowledges the superiority of visual information in the process of teaching swimming; due to an inferior perception of verbal information (acoustic disturbance of the environment lowers the student's perception). However, according to Orawiec[18], as many as 83% of all the signals that reach the recipient during the transfer of information are received by sight, whereas only 11% received by hearing. The use of audio-visual methods in teaching increases its effectiveness by 20–40%. It must be noted, however, that not all the signals that reach the sight organ are received, understood, processed and remembered. So the advantage of the sight analyzer over the hearing analyzer in communication activities does not mean that the receiver accepts the same amount of information that was sent by the sender.

Therefore, the role of the visual information transmitted during a physical education lesson, despite the short transfer duration times, is equally important. In an educational context using visual information, which invokes the possessed knowledge and the experience recorded in one's memory, broadens and expands associations and allows for the gathering of knowledge and recalling of information.

Proven analyses of the teacher's actions during physical education lessons have shown the dominant role of verbal information while visual information took from 5 to 10% of the lesson (45 minutes long).

Research on the role of verbal and visual information in raising the effectiveness of the didactic process in the teaching and learning of motor actions, has only concentrated on one of the information transfer channels: verbal or visual, leaving the second channel without the cause and effect explanation. The results obtained in the aforementioned research are not unanimous and their interpretation does not provide an explicit explanation.

The aim of our research is the experimental verification of teaching methods, with the use of word and visual images in the process of teaching–learning motor actions.

In order to empirically verify the research problem, the following hypothesis was formulated: the methods of information transmission used by the teacher in an intuitive way, without preparation and in accordance with the basic rules of receiving, reduces the effectiveness of the process involved in teaching–learning motor activities in swimming.

The following research questions were formulated:

1. Which of the methods of information transmission (verbal or visual) used to lead the experimental groups, prepared according to the basic rules of information theory, has a greater influence on the effectiveness of the teaching–learning of motor actions in swimming?
2. How the effectiveness of learning the motor action during the experiment is shaped (expressed by the accomplishment of the lesson objectives)?

[18] Orawiec W., Audiovisual Didactic Tools in Sports and Physical Education [in Polish], AWF, Katowice, 1986.

MATERIALS AND METHODS

The research was carried out on 9-year old children, students from the second grade of primary schools in Wrocław. In the research, the process of teaching and learning the front crawl swimming technique we analyzed. The chosen swimming skill was a new activity for the second graders according to the program of teaching swimming. Five swimming instructors took part in the experiment, as well as graduates of the University School of Physical Education, who had qualifications to teach swimming. The level of work experience ranged from 5–20 years and consisted of 3 female and 2 male teachers.

In order to examine the influence of the intentionally chosen and prepared verbal and visual information on the motor actions of the teaching–learning process in swimming, we conducted a pedagogical experiment banding the students into three groups:

- Experimental Group I – verbal and visual information transmission which was prepared according to the criteria of information theory was used – 52 students;
- Experimental Group II – verbal and visual information transmission which was prepared according to the criteria of information theory with a greater amount of visual information transmission was used – 53 students;
- Control Group – in which the visual and verbal transmission of information was presented in the traditional way – 53 students.

The experiment was performed over seven consecutive lessons where the students were taught a standard swimming technique (front crawl). In all the groups, the children were taught the same motor action while retaining identical teaching conditions and the same number of lessons (7). During the lessons, identical topics and objectives were completed. All the lessons finished with a test which was an assessment of the accomplished objectives.

Each lesson was entirely recorded on a video tape. It included all the pedagogical behaviour of the teacher during the lessons as well as the actions of the students. Transmission of teacher's verbal information to the students was registered by a digital tape recorder placed on the teacher's chest.

The teacher responsible for teaching experimental groups I and II, prepared the verbal and visual information which constituted the operand of the experiment, relied on multiple discussions with the author, prepared auxiliary materials (presence sheet, lesson scenarios) as well as didactic materials (multimedia presentations, charts presenting certain elements of front crawl, technique patterns). Detailed, precise explanations of the teacher's didactic actions took place before the research.

During the first ten minutes of each lesson, known as the lead-in part, the teacher explained the newly introduced technique element. Depending on the lesson scenario, the teacher used a previously prepared description, briefing, instructions, demonstrations as well as front crawl methodology charts and the multimedia presentations. Particular attention was paid to eliminating the most frequently appearing difficulties that the children had, with respect to the receipt of information, due to the concentration problems, freedom of screen observation, proper sound perception or access to the teacher.

Due to the verification of the assumptions in experimental groups I and II, in which verbal information was transmitted in accordance with the basic criteria of information theory, which in turn suggests a high level of efficiency in teaching, the following procedure was used:

The delivery of verbal information by the teacher had an explicit goal: the efficient and effective reception of information by the student. All verbal expressions that were to lead to the completion of the goal of the lesson, the teacher delivered by the means of verbal description (the description of the motor action), the accompanying commentary (in the form of additional clarifications during the performance of motor activity), verbal instructions (used before operations and during their duration), and commentary and discussion (additional transfer of information after the completion of tasks). The content of these expressions related to the topic and purpose of the lessons, error correction, referring to the previously acquired knowledge and skills. This information was conveyed to the student by the teacher in such a way, as to be semantically understood, have a logical sequence and be able to truly reach the student. Therefore, the teacher was to carefully choose and use verbal expressions that were clearly understood and interpreted by the recipient. The method of communication was limited to a minimum; the teacher expressed simple sentences so that pupils could understand them using their own perceptual abilities. Also the number of sentences was significantly reduced, following the principle of terseness, in order to ensure that the information effectively reaches the student.

The verbal information that relates to the explanation of the course of motor activity is associated with a specific order of spoken phrases, which give the exact sequence of motor actions. In order to achieve this, the teacher used the taught motility pattern, which was formed by Czabański, then made the division into sensorimotor sequences, or "basic configuration steps, bounded by two decisive points, between which there shall be no other decision made in the structure of the sensomotoric system"[19], so that in the following stage, the teacher would be able to specifically adapt the order of verbal information describing the sequences of movement. This is the condition of compatibility of the verbal description of motor activity with the presented motility model. Then the teacher selected and used such words in the description of activities, which enabled its correct implementation by the student. No less important was the manner of its transmission, which did not generate any disturbances in the flow and reception of the information.

The preparation of visual information in the experimental groups was based on the fact that, above all, the teacher had established and used in the experiment a common and understandable system of signs for the sender and receiver. The teacher adapted the number and duration of the shown exposures to the ability of conscious image reception for the student of an early school age. This demonstration captured as little information as possible over the longest time period (it was deliberately slowed down) therefore, the teacher was able to explain in detail the structure of the motor activity being taught, by differentiating particular sensorimotor sequences with consistent patterning. By doing this, the teacher assured that the recipient was in the correct mindset to take into account the cognitive

[19] Czabański, op. cit.

experience and their own perceptive abilities. It means that the teacher presented from 2 to 7 items that the student was able to remember. In addition, the entire course of the taught motor action was presented, in its natural pace and rhythm, taking into consideration that the course needs to be presented in appropriate coordination.

The difficulty level of the demonstration in such a way, depicted the structure of the action taught, in order to adapt it to the student's motor abilities, while the teacher controlled its effectiveness, throughout the demonstration, taking into account the feedback from student. The demonstration was presented immediately prior to the exercise of a motor task in order to maintain maximum accuracy of the image of action performed for the student. It should also be added, that the organization of the location for the demonstration, was dependent on its type.

RESULTS

During the experiment the effectiveness of the teaching process was expressed by the degree to which the group was able to achieve the objectives of the lessons. After every lesson, the teacher registered the child's results on an observation sheet. The results were expressed using the 0–1 grade system, where 0 meant that the objective was not fulfilled, and 1 that the objective was fulfilled. The effectiveness of the teaching–learning process of front crawl in the said pedagogical experiment, was measured by the summary number of the fulfilled lesson objectives during the experiment (Fig. 1).

The highest level of effectiveness in the teaching learning process of the front crawl stroke was observed in experimental group II, in which the operand was the verbal and visual information transmission, with the visual information taking the predominant role. The number of students who fulfilled the lesson objectives

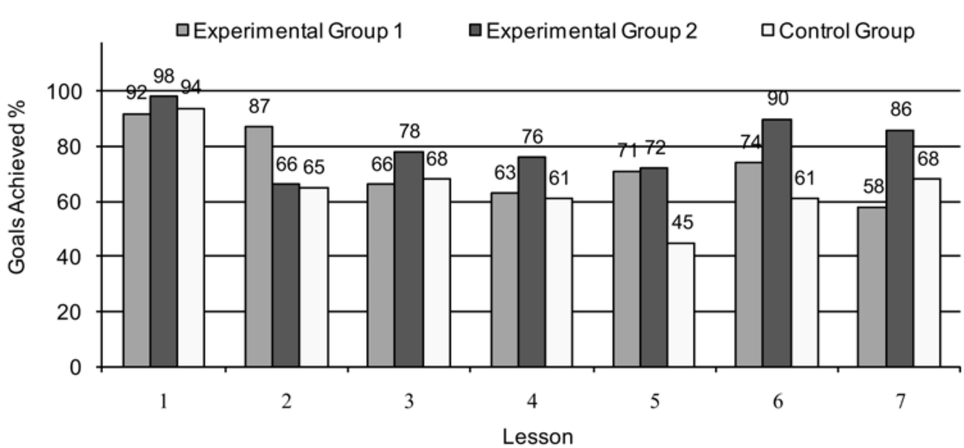

FIGURE 1. Percentage of the fulfilled objectives of the individual lessons in experimental group I, experimental group II and control group

in experimental group II fluctuated around 66% in the second lesson and 98% in the first lesson. The second lesson was the only lesson during which we did not observe a percentage advantage over experimental group I and the control group. In the remaining cases, the effectiveness of fulfilling the lesson objective was the highest in experimental group II. A comparison of the level in which the objectives were fulfilled in the experimental group I, where the information was transmitted visually and verbally according to the information theory, with the control group, does not show a consistent relationship. The effectiveness of fulfilling the objectives of lessons number one, three and seven, was higher in the control group. Although the difference was not significant in the case of lesson one and three (in both cases it was 2%), in the lesson seven it was 10%. Moreover, considering the lesson objectives determined by the experiment – especially lesson six and seven, in which participants were intended to complete the whole motor action, i.e. swimming a certain length full stroke, we could expect concurrent results. Meanwhile, the objective of lesson six was fulfilled by 74% of the students in experimental group I and 61% in the control group. While the objective of lesson seven was achieved by 58% and 68% of the students respectively. At this stage, we can assume that such a situation could be the result of the distance that the students had to swim, or the level of stress on students due to the recording of the swimming technique.

DISCUSSION

The results presented in the research encourage an extension of the means and methods used most frequently by physical education teachers when teaching motor education. The substitution of the dominant methods of information transmission, based on visual and hearing analyzers, with the methods which activate the interpersonal actions of the teachers, is based on their communicative competence, experience and knowledge of the student's personality. Perhaps the teacher's attention should be directed towards didactic communication, which in turn would highlight the value of the teacher as a dialogue partner, who creates and leads the student in a meaningful manner, with respect to motor skills education, while simultaneously transmitting knowledge and experience which is crucial in shaping the student's beliefs and attitudes.

CONCLUSIONS

1. The highest level of effectiveness when teaching–learning the process of the front crawl was observed in experimental group II, where the verbal and visual transmission were prepared according to a criteria of information theory with the predominant share of visual transmission.
2. The preparation of visual and verbal information transmission, according to information theory, caused the increase in the effectiveness of the process of teaching–learning motor skills.

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Effectiveness of learning to swim and the level of coordination of motor abilities

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INTRODUCTION

Much research has been done on the process of learning. The notion of learning itself may not be defined unequivocally, therefore there are many definitions.

According to the German educator Gloeckel, learning is about acquiring knowledge, skills and attitudes[1]. Postman and Weingärtner claim that learning occurs when expected changes occur[2]. Gagné, Briggs and Wagner point that changes that have occurred in the area of reacting to environment should be relatively stable[3]. The same is postulated by Treml, who additionally defines their stability and long lasting effect, therefore short lasting changes are not accounted for with respect to learning (e.g. changes caused by tiredness), but only those, which are characterized by their long lasting nature and permanence[4].

This notion is approached differently by Stermberg, who gives emphasis not to changes in behavior, but to changes occurring in individuals. The author sees a difference between learning and behavior. According to Stermberg learning is not always reflected in behavior and may occur without any changes occurring. He calls such manner of acquisition subliminal learning[5].

For Tomaszewski, learning is a process that leads to modification of individual's behavior; this modification characterizes organism during a certain period and occurs due to previous experience[6]. Schmidt also uses the importance of previous experience. In the course of motor learning he defines a cognitive phase (what to do?), association phase (how to do it?), and autonomous phase, where redundant movements are reduced and necessary information is processed[7].

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1 Gloeckel H., Vom Unterricht. Lehrbuch der allgemeinen Didaktik, Klinkhart, Bad Heilbrunn, 1990.

2 Postman N., Weingärtner C., Teaching as a subversive activity, Delacorte Press, New York, 1969.

3 Gagné R., Briggs L., Wagner W., The principles of didactic desing [in Polish], WSiP, Warszawa, 1992.

4 Treml A.K., Lernen, [in:] Krüger H.H., Helsper W. (eds.), Einführung in die Erziehungswissenschaft, Budrich Verlag, Opladen & Farmington Hills, 2006.

5 Stermberg R.J., Introduction to psychology [in Polish], WSiP, Warszawa, 1999.

6 Tomaszewski T. (ed.), Psychology [in Polish], PWN, Warszawa, 1975.

7 Schmidt R.A., A schema theory of discrete motor skill learning, *Psychological Review*, 1975, no. 82, pp. 225–260; Schmidt R.A., Motor and Control Learning, Human Kinetics, Champaign, 1988; Schmidt R.A., Motor Learning and Performance, Human Kinestics, Champaign, 1991.

In a broad sense the term “learning” is also understood to be synonymous with the term “memory”. This is so because, one and the other, may be characterized on the basis of changes in behavior[8].

For physiologists the process of learning consists in increasing efficiency of synapse connections and reducing the physiological cost put into the activity performed[9]. Learning depends on the flexible nature of the nervous system which plays a crucial role in all changes in behavior[10].

In new theories the difference between learning an action and mental learning is not clearly seen. Understanding the process of acquiring motor abilities proves that the process is complex and highly organized. It requires the creation of plans and programs of movements which have to be based on close analysis, thinking and cognitive processes, which contributes to effective action[11].

For Kotarbiński, action is effective when it leads to a desired outcome. The aim should be as close to a desired pattern as possible, or it should not vary too much. The less the creation differs from the pattern, the better the action has been performed[12].

However, the effectiveness of the action is to a large extent dependent on motor abilities, which determine efficiency of the action.

Raczek defines motor abilities as an array of individual physical and mental characteristics which develop on the basis of innate biological abilities and, which determine effective performance of the task[13].

For Szopa motor abilities mean, “a complex of predispositions integrated by a common, dominating biological basis and the kind of movements shaped by genetic and behavioral factors and remaining in interaction”[14].

Osiński claims that motor abilities are, “a set of individual characteristics determined by the structure, energy processes and movement steering and regulation which characterize the level of ability to effectively perform a given movement”[15]. Thus, the function of the organism is the basis for the motor abilities of an individual.

Fidelus and Gundlach similarly claim that the level of motor abilities depends on the level to which the morphological, physiological and mechanical structures have evolved. However, they also point out that mental and social features play a significant role[16].

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8 Włodarski Z., Psychology of learning. Tome I. 2nd ed. expanded and updated [in Polish], Wydawnictwo Naukowe PWN, Warszawa, 1996.

9 Brooks G.A., Fahey T.D., Exercise physiology: human bioenergetics and its applications, Macmillan, New York, 1985.

10 Zatoń K., Zatoń M., The significance of words in teaching and improvement of technique in sport, [in:] Zatoń M., Jethon Z. (eds.), Acitve movement in the light of physiological research and the promotion of health [in Polish], AWF, Wrocław, 1998, pp. 63–68.

11 Guła-Kubiszewska H., The deficit of verbal and visual information and the effectiveness of learning movement activity, [in:] Koszczyc T. (ed.) Didactics of physical education [in Polish], AWF, Wrocław, 1997.

12 Kotarbiński T., Treaty of good work [in Polish], Ossolineum, Wrocław, 2000.

13 Raczek J., Motor skills in children and young people – theoretical aspects and methodological implications [in Polish], AWF, Katowice, 1986.

14 Szopa J., Outlines in anthropomotorics [in Polish], AWF, Kraków, 1993.

15 Osiński W., Issues in human motor skills [in Polish], AWF, Poznań, 1991.

16 Fidelus K., Attempts to establish the basic motor factors influencing sporting results [in Polish],

According to Malinowski, motor abilities determine individual's potential movement abilities; an individual, without learning the movement, should possess a certain level of strength, speed, stamina and agility[17].

According to Raczek[18], motor abilities are a complex of individual predispositions which develop on the basis of innate genetic characteristics and guarantee the quality of the activity and its final effect. Among motor abilities the author specifies are, fitness abilities (energy), which consist mostly of energy and morphological/functional predispositions, coordination abilities (information), which make up neurosensory and mental predispositions, as well as complex predispositions (hybrid), which are not much determined by coordination and fitness abilities.

Coordination abilities reflect the complex interaction between neuropsychological processes, which allow for effective steering and regulation of an individual's movement activities. The differences between the level of given motor abilities is why individuals differ.

The notion of specific coordination abilities was first determined by American researchers in the course of studies and statistical analyses[19].

In Europe, the aspect of motor abilities coordination was studied by Hirtz[20] among others, who determined five basic coordination abilities for the needs of school children: a complex body reaction, spatial orientation, kinesthetic differentiation, a sense of balance, and the sense of body rhythm. In 1981, Blume added the ability to join movements and the ability to adjust movements[21]. In 1995, Starosta completed the list of abilities by adding: cooperation, movement distinctiveness, muscle relaxation, and in 1998, the ability of movement summarization[22].

Kinesthetic ability of movement variation is about having a proper perception of force, time and space, which take into account most effective performance of motor activity, allowing one to achieve optimum efficiency with the lowest effort. The ability to sustain balance allows one to keep static balance (stable body position) and dynamic balance (keeping balance during and after performing of movement activity). The ability to react quickly allows one to perform immediate ac-

Roczniki Naukowe AWF w Warszawie, 1972, 16, pp. 143–160; Gundlach H., On the dependency between physical talent and ability, [in:] Fidelus K., Symposium on theory and technique in sport [in Polish], SiT, Warszawa, 1970, pp. 185–194.

17 Malinowski A., Issues of norms in biology and medicine [in Polish], *Przegląd Antropologiczny*, 1982, no. 1–2, pp. 87–106.

18 Raczek J., Concepts of structuring and classifying human motor skills, [in:] Osiński W. (ed.), Human motor skills – their structure, variability and considerations [in Polish], AWF, Poznań, 1993, pp. 63–80.

19 Fleishman E., The structure and measurement of physical fitness, Prentice-Hall, Englewood Cliffs, 1964.

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22 Starosta W., Koordinations und Konditionsfähigkeit bei Mannschaftsspielen, [in:] Bergier J. (ed.), Science in sport Team Games, AWF, Warszawa, International Association of Sport Kinetics, Biała Podlaska, pp. 69–104; Starosta W., Correlation between Co-ordination and Physical Abilities in the Theory and Practice of Sport Training, [in:] Blaser P. (ed.), Sport Kinetics '97 "Theories of Human Motor Performance and their Reflections in Practice", Schriften der Deutschen Vereinigung für Sportwissenschaft, Band 98, Czwalina, Hamburg, 1998, vol. 1, pp. 57–69.

tion at a given signal. The level of this ability is described by the time between the beginning of the action and its completion. The shorter the time, the quicker the reaction. Time and space orientation allows one to determine the body position during the performance of the action in relation to a given action framework (e.g. a field/court, an opponent). The ability of rhythmization allows one to perform a given action in an ordered way, which means taking into account a proper rhythm of consecutive fragments of the movement. The ability to adjust permits one to implement an optimum program of action, or allows one to change it, should this be needed. The basis of this ability is the process of acquiring and processing visual information, as well as verbal and kinesthetic information. The ability to conduct feed back permits one consciously organize body movements, and allows one to integrate them in time and space. The ability of movement symmetrization lets one transfer the movement technique from one part of the body to the other, which requires the cooperation of both hemispheres. The ability to make distinctive movements allows one to suggestively express emotions, simulated by music, through performing aesthetic movements. The ability to relax muscles consists of relaxing those muscles that do not take part in the movement activity, as well as relaxing those that take part in the movement activity, right after its performance. The ability of muscle cooperation allows one to fine-tune one's own movements with those of a partner, anticipating the partner's movements, and immediate modification of one's own movements depending on the situation[23].

Motor abilities coordination plays a different role in different sport disciplines. In case of individuals who do sports related to swimming, the most important is the "feel for the water", that is a way in which an individual adapts to water environment. This is an indicator of sports form[24]. The most important components of "feel for the water" according to Starosta and Rostkowska[25], are the speed of reaction, ability to maintain balance, ability to kinesthetically differentiate movements of limbs and the ability of space and time orientation.

All the above mentioned abilities have contributed to the formulation of the question.

Question

1. Is there a correlation between motor coordination abilities and the level of mastering swimming movements and technique?

MATERIAL AND METHODS

SELECTION OF PUPILS FOR THE RESEARCH

74 pupils of the third grade from the Primary School No 5 in Opole and 62 pupils of the third grade from the Primary School No 12 in Kędzierzyn-Koźle took part

[23] Starosta W., Coordinated motor skills. Significance, structure, considerations and formation [in Polish], Międzynarodowe Stowarzyszenie Motoryki Sportowej, Warszawa, 2003.

[24] Ibid.

[25] Starosta W., Rostkowska E., The Structure of Water Feeling and the Hierarchy of its Component Elements in the Opinion of those Training Swimming, [in:] Proceedings of the 6th Sport Kinetics Conference, Ljubliana University, Ljubliana, 1999, pp. 332–335.

in the research. Both schools apply similar teaching methods and operate in similar facilities (depth of the swimming pool at the shorter end is 120 centimeters).

The selected pupils took part in mandatory swimming lessons. Classes were held once a week and lasted 45 minutes. As motor, somatic and intellectual differences do not play a major role in teaching physical education between the sexes at this age, the research was conducted on both groups without separating boys from girls.

The main criterion to qualify a person for the experiment was the ability to swim. However, before the test was started, all the pupils were subject to a preliminary adaptation to the water environment, which lasted for four consecutive lessons. Its aim was to make sure the level of all the swimmers was similar. A person was considered adapted to the water environment when they could perform the following tasks: jump into the water (in style and from any place of the pool), submere the head under the surface and simultaneously exhaling air, and gliding on the breast and back after a kick off (both legs) from the wall of the pool.

A total of 122 pupils were asked to participate in the experiment. The second group did not present higher swimming skills than the first group. The two groups were then divided, at random, into control and experimental group. Unfortunately, after the experiment only 86 pupils could be subject to the final diagnosis (40 in the experimental and 46 in the control groups), due to the absence of many pupils.

SELECTION OF TEACHERS FOR THE RESEARCH

Teachers of physical education with various experience participated in the project (7, 11, 18, 26 and 31 years in the job). They all were qualified swimming teachers holding degrees in PA; they also worked as swimming instructors. All of them ran classes both in the experimental and control groups; moreover they had not been informed of the aim of the research.

RESEARCH METHODS

A pedagogical experiment was applied in the research. The pupils subject to the test were divided into experimental and control groups. The same teachers ran classes in both groups. The lessons took place once a week, each of them lasted 45 minutes; the experiment ran for eight consecutive lessons, the eight lessons being devoted to testing swimming skills in back crawl. The teaching material in both groups was the same.

The researchers chose the back crawl as the skill to be tested, as a natural interchanging limb movement characterizes this style; the style allows easier breathing and contact with the teacher is facilitated. Additionally, the positioning of the body allows the teacher to communicate visually with the pupil (gestures) and lets the pupils correct errors they make immediately.

The difference between the experimental and control groups consisted of the introduction of an independent variable.

This independent variable was immediately communicated using a gesture right after an erroneous movement was seen. Only those elements, which were not accepted in a given movement were corrected. Each of the errors was corrected using a specific gesture intended to signal its correction[26].

Before each lesson, the pupils in the experimental group were familiarized with the gestures that would occur during the class. Moreover, the pupils were advised that they should observe the teacher during the whole duration of the lesson, and react accordingly to the gestures from the teacher, while at the same time, correcting any errors. On the other hand, in the control group, incorrect movements were corrected using verbal communication.

After the experiment was completed, all the participants were filmed to assess the accuracy of their crawl (backstroke) swimming technique, and compare it with the set pattern. To do this a filming method was used, as well as the swimming accuracy rate, as described by Zatoń[27].

In this experiment, the closer the activity performed was to the set pattern, the better it was mastered. The rate determining swimming accuracy was calculated for each participant of the test.

Swimming Accuracy Rate W*op*

$$W_{op} = \frac{l_{pw}}{l_c} = \frac{l_c - l_o - l_p}{l_c}$$

where:

W_{op} is swimming accuracy rate which accounts for the number of sequences missed and done incorrectly;

l_{pw} – the number of sequences done correctly by the tested person;

l_c – the number of total sequences (in the pattern);

l_o – the number of sequences missed;

l_p – the number of sequences done incorrectly.

Tests determining the level of motor skills coordination.

As acquiring new movement depends largely on individual movement ability, motor tests were performed alongside the experiment. Their aim was to compare the level of specific coordination abilities in the control and experimental groups.

In the selection of tests for general fitness to diagnose specific motor abilities we applied already existing knowledge as published by Hirtz[28], Raczek and Mynarski[29], Raczek, Mynarski and Ljach[30]. Checks were done after a short warm up and they were not preceded by a big physical effort. The tests included testing the speed of reaction of the whole body (Hirtz's test), ability to react quickly

[26] Burzycka-Wilk D., The effectiveness of immediate information in the process of teaching motor skill activity, Doctorial dissertation [in Polish], AWF, Wrocław, 2008.

[27] Zatoń K., The effectiveness of verbal information while teaching motor functions in swimming [in Polish], *Rozprawy Naukowe AWF we Wrocławiu*, 1981, no. 16, pp. 217–283.

[28] Hirtz P., Struktur und Entwicklung koordinativer Leistungsvoraussetzungen bei Schulkindern, *Theorie und Praxis der Körperkultur*, 1977, no. 7, pp. 724–733.

[29] Raczek J., Mynarski W., Coordination and motor skill abilities in children and young people [in Polish], AWF, Katowice, 1992.

[30] Raczek J., Mynarski W., Ljach W., Theoretical-empirical basis for the formation and diagnosis of coordinated motor ability [in Polish], AWF, Katowice, 1998.

(Ditrich's test – catching of a stick), ability to kinesthetically differentiate upper limbs (catching a suspended ball) and lower limbs (jump from the box), spatial orientation ability (throwing a ball into a suspended basket) and the ability to maintain dynamic balance (walk on the balance beam).

RESULTS

To compare a level of particular coordination abilities in both groups, analysis of variance was applied (ANOVA). The results of the test pointed that both groups were similar in all tested characteristic. Differences that were seen in the following tests were not statistically important: Hirtz's test, ability to kinesthetically differentiate upper limbs (test with a cup), spatial orientation (throwing a ball into a basket), ability to kinesthetically differentiate lower limbs (jump from the box) and the ability to maintain dynamic balance (walk on the balance beam). Those statistically important were seen in the test gauging the ability to react quickly (Ditrich's test – catching a stick) where the control group excelled. This is shown in Tab. 1.

Moreover, the correlation was tested between swimming accuracy rate and selected motor abilities. To do this Spearman's rank correlation coefficient was applied[31].

In the course of the analysis it turned out that there was only a statistically important difference between swimming accuracy indicator and Ditrich's test at a level of $p \leq 0.05$. A correlation between the swimming accuracy indicator and other motor abilities were not seen (Tab. 2).

DISCUSSION

Movement coordination is the least researched aspect of motor structure. In recent years an opinion has been widespread that it is composed of a set of more basic correlated coordination abilities. The basic coordination abilities are intertwined and their level is equal. Not all definitions of coordination abilities are entirely correct (especially these proposed recently) therefore, they require a precise description and a new role and place is needed for them, in particular sports disciplines. The lack of precise information makes it difficult for researchers to accurately determine the optimum level of each of these abilities of efficiently learning[32].

According to Szopa, motor abilities are determined by genetics and also by phenotype specifics (changing in the environment), therefore to achieve a desired effect in sports, one need not be born with a perfect set of features[33]. Osiński

[31] Sidney S., Castellan N.J. Jr, Nonparametric statistics for the behavioral science, McGraw – Hill Book, New York, 1956, p. 312.

[32] Starosta, Coordinated motor skills…

[33] Szopa J., Considerations, indications and structures of human motor skills in the light of the opinions of the "Krakow School" [in Polish], *Antropomotoryka*, 1995, no. 12–13, pp. 59–82.

TABLE 1. Correlation of swimming accuracy rate and motor coordination abilities

Variable	Mean		t	df	p	Standard deviation	Standard deviation	Quotient F	P probability
	control	experimental				control	experimental	variance	variance
Speed test (Hirtz's test)	1.884615	1.92800	–0.82866	44	0.411767	0.149753	0.205544	1.883916	0.137978
Quick reaction ability	**24.30769**	**30.00000**	**–2.05147**	**44**	**0.046204**	**7.734438**	**11.08342**	**2.053476**	**0.092606**
Upper limbs kinesthetic differentiation ability	0.730769	1.35000	–1.63135	44	0.109955	1.115623	1.460894	1.714755	0.205477
Spatial orientation ability	1.115385	0.95000	0.54619	44	0.587695	0.993053	1.050063	1.118113	0.782009
Lower limbs kinesthetic Differentiation ability	8.038462	9.55000	–1.20711	44	0.233841	3.778685	4.718106	1.559028	0.295651
Dynamic balance aintenance ability	23.11538	26.25000	–1.77775	44	0.082356	6.981845	4.153312	2.825864	0.023422

* in bold statistically important data at a level of $p \leq 0.05$

TABLE 2. Correlation of Spearman's Rank Coefficient of swimming accuracy and selected motor coordination skills

	N	R	t(N-2)	Level p
	Important	Spearman		
Swimming accuracy rate & and speed test (Hirtz's test)	86	–0.05276	–0.48424	0.62947
Swimming accuracy rate & quick reaction ability	**86**	**0.21852**	**2.05234**	**0.04325**
Swimming accuracy rate & upper limbs kinesthetic differentiation ability	86	0.11455	1.05681	0.29363
Swimming accuracy rate & spatial orientation ability	86	0.00977	0.08957	0.92884
Swimming accuracy rate & lower limbs kinesthetic differentiation ability	86	–0.05488	–0.50377	0.61574
Swimming accuracy rate & dynamic balance maintenance ability	86	0.02939	0.26947	0.78823

* in bold statistically important data at a level of $p \leq 0.05$

agrees with Szopa and claims that motor abilities determine the way a particular action is performed, however they should not be given too much emphasis[34]. The results of earlier studies support this statement, as they show that pupils achieved a higher swimming accuracy indicator, independent of the level of accuracy they achieved in particular motor coordination abilities.

Szopa does not agree with this, and points to the fact that there is a need to do research to determine the level of a swimmer's potential motor abilities. He stresses that the more skilled the swimmer, with respect to movement coordination, the shorter the period of mastering skill and achieving best results. Thus, a necessity arises to determine the particular abilities necessary in particular disciplines. Unfortunately, coordination abilities are not isolated in the course of performing an activity, that is why it is difficult to classify them, measure them and later interpret them[35].

Despite all difficulties, researchers attempt to determine the most important motor abilities for particular sports. Swimming requires a particularly high level of "feel for the water" as a precondition for a person's adjustment to operating in the water environment. It also plays an important role during the stage of learning to swim and mastering swimming techniques, and especially in achieving masters level[36], as it allows for rational movement in the water with the use of minimum energy. However, "feel for the water" may only occur in the water environment, therefore, it is difficult to assess it before selecting a potential swimmer.

In this research both tested groups featured a similar level of swimming motor abilities. The only difference (statistically relevant at the level of $p \leq 0.05$) was seen in the test gauging the ability to react quickly (Ditrich's test) where the control group excelled. However, it may not be clearly determined that higher ability to react makes it harder to acquire new motor abilities, because this requires additional research.

Visual information, communicated by means of "the language of gestures", has an influence on the accuracy of learning swimming motor activities. In the teaching swimming motor activities, visual information is more efficient[37].

In theory and practice of professional sport, it has recently been more important to look for new methods of achieving desired results. Incessant increase in greater training effort has a negative outcome, as young sportsmen no longer want to devote all their life and effort to difficult training chores. They often give up sport and this, in itself, is the greatest failure of coaches and trainers. Therefore, increasing efficiency of training at similar effort, is an important alternative for the future of professional sport[38].

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[34] Osiński, op. cit.

[35] Szopa, Outlines in anthropomotorics…

[36] Starosta W., Rostkowska E., Selected aspects of "Water feeling" problem in swimming, [in:] Proceedings of the 6th Sport Kinetics Conference…, pp. 328–331.

[37] Burzycka-Wilk D., Effectiveness of visual information in the process of teaching swimming motor activities, *Human Movement*, 2010, vol. 11, no. 2, pp. 184–190.

[38] Starosta W., Coordinated motor skills…

CONCLUSIONS

1. The only statistically relevant correlation seen was between swimming accuracy rate and Ditrich's test, which describes fast reaction abilities.
2. No correlation was found between other motor coordination abilities and swimming accuracy.

CHAPTER II

BIOLOGY AND BIOMECHANICS IN COMPETITIVE SWIMMING

An attempt at rationalizing swimming training efficiency

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INTRODUCTION

Every movement of the human body is related to chemical energy change (potential); energy stored in the organism is transformed into kinetic energy. Research has been going for some time now on the loss of the internal energy, referred to as cost, and also external energy – referred to as work. One of the most universal indices of cost is oxygen uptake, the study of which is not easy (despite the latest technological applications)[1].

Muscle energy resources allow humans to perform physical work, and the most important group of substrates in swimmers' effort, are carbohydrates. They are the source of glycogen replenishment which is used in long-lasting and intensive effort. This multi-sugar is stored in the organism in muscles and in the liver. For athletes, glycogen stored in muscles is most crucial because when using the glycogen stored in the liver, one ATP particle is used to break up stored fuel. Among many aims of the sports training in endurance disciplines, one of the most important objectives is the increase of the multi-sugar pool stored in the organism. While a great amount of glycogen is depleted in training, in restitution time, and with the application of proper diet high in carbohydrates, it will be re-synthetized; its level will be higher than before the effort. During restitution period, after a long-lasting effort, one may achieve a higher level of this multi-sugar than before the training (this also often happens after a diet high in carbohydrates is applied)[2]. This replenished state, however, returns to the onset stage, therefore it is important in swimming to perform another training in the period called glycogen super-compensation. Inducing such reactions (also with the use of diet) may lead to negative

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1 Shephard R.J., Astrand P.O., Endurance in Sport, Blackwell Scientific Publications, Oxford, 1992, pp. 46–60.

2 McInerney P., Lessard S.J., Burke L.M., Coffey V.G., Lo Giudice S.L., Southgate R.J., Hawley J.A., Failure to repeatedly supercompensate muscle glycogen stores in highly trained men, *Medicine and Science in Sports and Exercise*, 2005, vol. 37, no. 3, pp. 404–411; Parra J., Cadefau J.A., Rodas G., Amigó N., Cussó R., The distribution of rest periods affects performance and adaptations of energy metabolism induced by high-intensity training in human muscle, *Acta Physiologica Scandinavica*, 2000, vol. 169, no. 2, pp. 157–165; Walker J.L., Heigenhauser G.J., Hultman E., Spriet L.L., Dietary carbohydrate, muscle glycogen content, and endurance performance in well-trained women, *Journal of Applied Physiology*, 2000, vol. 88, no. 6, pp. 2151–2158.

results, such as pancreas damage. However, well trained athletes may produce a long lasting effort (sometimes an hour or more) from the energy stored in muscles; this allows them to cover any distance in classic swimming, e.g. in training.

Swimmers benefit from the energy generated not only from carbohydrates changes, but during long-lasting effort performed at moderate intensity (such as training) most energy is generated from fat. Although swimmers cover most of the distance with high intensity (at times exceeding 90% VO_{2max} (in our own studies) where ATP is generated from anaerobic glucose, swimming training also improves metabolism of fatty acids. As a result, contribution of fat as a source of energy rises, which helps save the glucose pool. An increase in the use of fats during effort is beneficial in another aspect, i.e. they are practically non-depletable and may provide energy for many hours of effort. According to Brouns and Van der Vusse[3] the following influences proper fat change:

– Capillarization of heart and muscles and increased blood flow;
– Triglicerids lipolysis in fat tissue and fatty acid transportation from plasma to sarcoplasm of muscle fibres;
– Hydrolisis speed internal cell triglicerids;
– Fatty acids transportation through the mitochondrial membrane;
– Oxygen enzyme activation;
– Hormonal adaptation: sensitivity to catecholamine and insulin.

The only way to improve fat utilization is long-lasting effort. Hawley et al.[4] conducted the analysis of known strategies leading to in increase the use of fat resources during effort. The aspects they discussed cover:

– Aerobic training;
– Caffeine consumption;
– L-carnityne consumption;
– Triglicerids (medium chain – MCT) consumption;
– Triglicerids (long chain – LCT);
– Effort on empty stomach.

Some scientists question the rationality of most of the above mentioned methods and claim that the best way to improve fat metabolism is only through endurance/aerobic effort. Desired effects are as follows: improved supply and usage of oxygen, improvement of fatty acid flow to mitochondria, increase in the number and size of mitochondria, activity of lipoprotein lipase, inner-muscle trigliceride oxydation and cholesterol VLDL[5].

The last energy source in long-lasting effort (training) are proteins. They are usually used as a "building material" for the organism: in building damaged muscle fibres, hormone and enzyme synthesis and immunology system elements. They

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[3] Brouns F., Van der Vusse G.J., Utilization of lipids during exercise in human subjects: metabolic and dietary constraints, *British Journal of Nutrition*, 1998, vol. 79, no. 2, pp. 117–128.

[4] Hawley J.A., Brouns F., Jeukendrup A.E., Strategies to enhance fat utilisation during exercise, *Sports Medicine*, 1998, vol. 25, no. 4, pp. 241–257.

[5] Hawley, Brouns, Jeukendrup, op. cit.; Kubukeli Z.N., Noakes T.D., Dennis S.C., Training techniques to improve endurance exercise performances, *Sports Medicine*, 2002, vol. 32, no. 8, pp. 489–509; Schrauwen P., van Aggel-Leijssen D.P., Hul G., Wagenmakers A.J., Vidal H., Saris W.H., van Baak M.A., The effect of a 3-month low-intensity endurance training program on fat oxidation and acetyl-CoA carboxylase-2 expression, *Diabetes*, 2002, vol. 51, no. 7, pp. 2220–2226.

may be used in order to obtain energy during effort, through stimulating hyperglycemic factor secretion, and they influence fat metabolism.

Conventionally, maximum oxygen uptake (VO_{2max}) is described as the ability of circulatory system to provide oxygen to working muscles and other organs at maximum effort. It is used as a measure of physical endurance, but also as a marker of health defects related to circulatory system insufficiency[6].

VO_{2max} may be measured only at maximum efforts which engage large muscle groups[7]. This parameter is often considered as the most important factor determining performance in swimming. It is especially important in the process of selecting swimmers who may achieve the best results in the future, and also when forecasting their development. Decreased level of VO_{2max} may be the signal that the swimmer is tired or over-trained. In practice, the maximum oxygen uptake is used while assessing training development. VO_{2max} is not the decisive factor in sports achievements, as it only describes efficiency of oxygen provision to the mitochondria, and it should not be considered as the equivalent to cellular metabolism efficiency. As the maximum oxygen uptake describes provision of oxygen to muscle cells, the following factors determine its value[8]:

– Hematological parameters (the number of red cells, hemoglobine concentration and Ht).
– Cardiac output. (Q) is the volume of blood being pumped by the heart, in particular by a ventricle in a minute. It limits cell blood flow, i.e. the amount of blood circulating in working muscles. Cardiac output is determined by the frequency of heart contraction and stroke volume, the increase of which is considered the most crucial factor in increasing VO_{2max}.
– Capillarization, i.e. the development of a capillary network of muscles and lungs.
– Lung diffusion capacity at the level of lung follicles and capillary vessels that feed muscle groups loaded and under effort.
– Maximum oxygen uptake is conventionally described by the Fick equation (after Levine)[9]:

$$VO_{2max} = (PRV - PSV) \times HR_{max} \times A\text{-}VD$$

where:
VO_{2max} – maximum oxygen uptake;
PRV – late diastole of heart volume;
PSV – end-systolic volume;
HR_{max} – maximum heart rate;
A-VD – arterio-venous concentration difference.

Among the parameters listed above, the one parameter that sets apart professional athletes from amateurs, is late diastole of heart volume. It limits the amount of blood that can flow into the left ventricle of the heart before contraction. It depends on the heart susceptibility, and above all on the susceptibility of pericardial

6 Levine B.D., VO_{2max}: what do we know, and what do we still need to know? *Journal of Physiology*, 2008, vol. 586, no. 1, pp. 25–34.
7 Joyner M.J., Coyle E.F., Endurance exercise performance: the physiology of champions, *Journal of Physiology*, 2008, vol. 586, no. 1, pp. 35–44.
8 Joyner, Coyle, op. cit.; Levine, op. cit.
9 Levine, op. cit.

sac which develops over the years of training. Low elasticity of the pericardial sac is considered to be one of the most important factors limiting cardiac output. The influence of the heart's susceptibility on cardiac output is described in the Starling equation, i.e. heart muscle contraction force depends on heart elasticity; the greater the latter, the larger the former proportionally[10].

Apart from the heart's susceptibility, transmural pressure also impacts greatly on its output. This pressure is generated between the atrium and ventricle. These cells relax very fast, in the case of the best athletes, after the miocites contract. The pressure gradient is generated, which is conducive to faster flow of blood through atrioventricular valves, from veins and left atrium to the left ventricle[11].

Late diastole of heart volume and arterio-venous concentration difference have slightly less impact here, and big differences between the best athletes and non-professionals, do not occur in this respect[12].

One of the factors influencing the level of maximum oxygen uptake is maximum heart rate. The value of this parameter is often lowered in the case of swimmers. Therefore, its increase at constant stroke volume may contribute to improvement of oxygen provision and – in consequence – impact sport performance. Decrease in the maximum heart rate is the effect of performing only aerobic volume trainings[13]. When this type of training takes precedence over other types, this impacts sympathetic part of the autonomous nervous system, which slows down heart rate frequency[14]. In order to maintain a desired level of this parameter (220 – age in years) one should introduce glycolic trainings, based on maximum intensity, and lasting 15 to 120 seconds[15].

Maximum oxygen uptake is at the level of c. 50–100% higher in case of athletes who do endurance sports, than in the case of individuals who do not train. The best endurance athletes (marathon, cycling, cross-country skiing, swimming) achieve VO_{2max} at a level of 70–85 ml/min/kg i.e. 5 l/min, however there were cases of people reaching 7 l/min, at cardiac output exceeding 42 l/min. The level achieved by women is 10% lower, which is caused by lower value of maximum lung ventilation, cardiac output, hemoglobin concentration and more fat tissue[16].

The level of maximum oxygen uptake is to a large extent hereditary. However, it is difficult to identify genes responsible for that. Great importance is ascribed to genes controlling angiotensin converting enzyme. High correlation is observed at the level of 0.6 between those who have these genes, and aerobic performance[17].

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10 Ibid.

11 Ibid.

12 Ibid.

13 Zatoń M., The value of physiological criterions in the control and regulation of sport training [in Polish], *Studia i Monografie AWF we Wrocławiu,* 1990, no. 22.

14 Zavorsky G.S., Evidence and possible mechanisms of altered maximum heart rate with endurance training and tapering, *Sports Medicine*, 2000, vol. 29, no. 1, pp. 13–26.

15 Zatoń, op. cit.

16 Mujika I., Padilla S., Pyne D., Busso T., Physiological changes associated with the pre-event taper in athletes, *Sports Medicine*, 2004, vol. 34, no. 13, pp. 891–927; Joyner, Coyle, op. cit.; Levine, op. cit.

17 Levine, op. cit.; Myerson S., Hemingway H., Budget R., Martin J., Humphries S., Montgomery H., Human angiotensin I-converting enzyme gene and endurance performance, *Journal of Applied Physiology*, 1999, no. 87, pp. 1313–1316.

However, there is also a group of athletes without those genes, who also achieve great sport results[18].

In order to achieve optimum VO_{2max} increase, more changes of the mechanisms determining this global parameter, are required. For example, improvement in cardiac output may not have any impact, if there are large limitations in gas diffusion at the level of lungs or cells. Improvement in diffusion at the lung level may occur along with blood transfusion or in treatment with derivative of human erythropoietin[19]. This may prove unsuccessful, however, as blood concentration leads to an increase in its viscosity, and hence, more mechanical resistance in its flow through blood vessels.

A popular method of determining VO_{2max} are progressive tests. In laboratory studies, it is conventionally assumed that maximum oxygen uptake occurs when VO_2 reaches plateau in relation to increasing load in the final part of the test. Many athletes do not meet this criteria, therefore it is assumed that VO_{2max} may be determined when dynamics of increase in oxygen uptake, decreases substantially in relation to the increase in external load. This "not-so-stringent" criterion may not be met by many athletes either. They stop the test at the moment of dynamic increase of VO_2. Such progress of the progressive test shows that there are insufficient developments in anaerobic efficiency. Moreover, stopping the test and effort may be the symptom of disorder in calcium secretion at the level of sarcoplasmatic reticulum, decrease in efficiency of sodium-potasium pump, or other mechanisms controlling Ph balance. Various metabolic factors may influence this, eg. occurrence of reactive forms of oxygen in mitochondria. At the muscle level, these factors are received by the nervous system (affarent arterioles) which is in charge of motor units recruitment[20].

Many authors have dealt with the impact of endurance training on oxygen uptake in effort. There are many works dealing with the issue of improving VO_{2max}, coupled with achieving better results in tests, after a training period, geared towards developing aerobic endurance[21]. Undoubtedly, it is crucial in the first stage of the training, to focus on long-lasting effort at low and moderate intensity. One of its results would be a substantial increase of maximum oxygen uptake[22]. Together with the increase of VO_{2max}, due to the aerobic training, maximum heart rate is lowered[23]. In the case of athletes with a lot of training experience, more VO_{2max} improvement occurs after focusing on intensive training work, with the use of interrupted training methods[24]. Excessively intensive training effort is ben-

18 Levine, op. cit.

19 Ibid.

20 Ibid.

21 Chtara M., Chamari K., Chaouachi M., Chaouachi A., Koubaa D., Feki Y., Millet GP., Amri M., Effects of intra-session concurrent endurance and strength training sequence on aerobic performance and capacity, *British Journal of Sports Medicine*, 2005, vol. 39, no. 8, pp. 555–560; Kubukeli, Noakes, Dennis, op. cit.; Messonnier L., Denis C., Prieur F., Lacour J.R., Are the effects of training on fat metabolism involved in the improvement of performance during high-intensity exercise? *European Journal of Applied Physiology*, 2005, vol. 94, no. 4, pp. 434–441; Zavorsky, op. cit.

22 Kubukeli, Noakes, Dennis, op. cit.; Zavorsky, op. cit.

23 Zavorsky, op. cit.

24 Gore C.J., Hahn A.G., Burge C.M., Telford R.D., VO_{2max} and haemoglobin mass of trained athletes during high intensity training, *International Journal of Sports Medicine*, 1997, vol. 18,

eficial, as many endurance athletes have recorded a substantial increase of this parameter in mid season, in comparison to a training period where load was greater (from c. 69 to 78 ml/min/kg)[25]. Similar results were achieved by another group of athletes. This parameter was measured in that group after 18 days of interval training at intensity close to 100% HR_{max} and after 10 days of decreasing loads.

Similarly, improvement in aerobic endurance due to intensive interval trainings has been observed in case of non-professionals (our own studies).

There are studies available that deal with the impact of training in conditions of higher VO_{2max} concentration oxygen of the air. A slight increase of this parameter was observed (in comparison to training performed in atmospheric air conditions) in response to oxygen trainings (intensive repetitions of 3–4 minute work) performed at an oxygen concentration of 60%[26]. However the difference was not statistically significant. On the other hand, other studies suggest that less glycogen is used in effort at a moderate or sub-maximal intensity, in conditions of hiperoxy (60% O_2) as compared to normoxy, which could lead to a conclusion that oxygen processes are more sufficient in these conditions. It was also established that an increase in oxygen uptake accompanies sub-maximal training[27].

In a situation when oxygen demand exceeds its supply, and the production of pyruvate can not be matched by the mitochondria for its oxidation, lactate production starts to increase. This in turn accumulates in blood, reching the level of c. 4 mmol/l of plasma. In approximation, reaching such a lactate concentration is reaching the anaerobic threshold. From now on glycogen changes accelerate (anaerobic) which leads to a sudden lactate accumulation in blood. At the same time, the level of pH decreases in muscles and in blood, and this information is transmitted and received by the central nervous system (OUN), which is one of the mechanisms of tiredness. The pace of work slows down, which is seen in cardiovascular reflexes from the autonomous nervous system[28]. The anaerobic threshold is usually accompanied by the maximum stroke volume (SVmax)[29]. The anaerobic threshold is characterized by the ability to transport lactate and hydrogen ions outside cells. This reflects the buffer capacity of muscles, capacity to oxidize lactate, mitochondrial enzyme activity and aerobic metabolism, which increase in groups of muscles under load[30].

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no. 6, pp. 477–482; Laursen P.B., Blanchard M.A., Jenkins D.G., Acute high-intensity interval training improves T[subvent] and peak power output in highly trained males, *Canadian Journal of Applied Physiology*, 2002, vol. 27, no. 4, pp. 336–348; Neary J.P., McKenzie D.C., Bhambhani Y.N., Effects of short-term endurance training on muscle deoxygenation trends using NIRS, *Medicine and Science in Sports and Exercise*, 2002, vol. 34, no. 11, pp. 1725–1732.

25 Hoogeveen A.R., The effect of endurance training on the ventilatory response to exercise in elite cyclists, *European Journal of Applied Physiology,* 2000, vol. 82, no. 1–2, pp. 45–51.

26 Perry C.G., Reid J., Perry W., Wilson B.A., Effects of hyperoxic training on performance and cardiorespiratory response to exercise, *Medicine and Science in Sports and Exercise*, 2005, vol. 37, no. 7, pp. 1175–1179.

27 Stellingwerff T., Glazier L., Watt M.J., LeBlanc P.J., Heigenhauser G.J., Spriet L.L., Effects of hyperoxia on skeletal muscle carbohydrate metabolism during transient and steady-state exercise, *Journal of Applied Physiology*, 2005, vol. 98, no. 1, pp. 250–256.

28 Joyner, Coyle, op. cit.

29 Lepretre P.M., Foster C., Koralsztein J.P., Billat V.L., Heart rate deflection point as a strategy to defend stroke volume during incremental exercise, *Journal of Applied Physiology*, 2005, vol. 98, no. 5, pp. 1660–1665.

30 Lucía A., Rivero J.L., Pérez M., Serrano A.L., Calbet J.A., Santalla A., Chicharro J.L., Deter-

There are various methods postulated to determine the exact moment when a sudden glycogen change occurs anaerobically. Various terms are also used. The most common method is the analysis of ventilatory parameters which determines ventilatory threshold (VT1) and anaerobic one (VT2) thresholds. Respiratory compensation point (RCP) is also discussed in the heart rate deflection point (HRDP)[31]. Other authors determine anaerobic threshold at points where acidity in blood reaches 2 and 4 mmol/l respectively – i.e. the lactate thresholds (LT1 and LT2)[32]. However, determining work intensity thresholds in such a way is often criticized, because lactate concentration at the level of 4 mmol/l does not occur in the case of all athletes at the same level of force used[33]. On the other hand, the moment when acid metabolism products increase in the blood (OBLA) is determined by taking it from capillary vessels, and as maximal lactate steady state, it is not ascribed to a constant concentration value of this metabolite[34]. Determining the above mentioned thresholds allows us to describe three intensity zones, postulated by Esteve-Lanao et al.[35]:

- Low intensity, below VT1 or below acidity of 1–2 mmol/l of blood.
- Medium intensity, between VT1 (or LT1) and VT2 (or RCP, AT, LT2, OBLA, MLSS).
- High intensity, above VT2 (or OBLA, LT2, AT, RCP, MLSS).

Another classification is also assumed for effort[36]:

- Zone I – efforts which lead to lactate concentration in plasma to the level of 4 mmol/l.
- Zone II – efforts in the zone of sudden lactate concentration increase. Acidification of 4–8 mmol/l.
- Zone III – efforts above the upper level of dynamic lactate increase, i.e. above 8 mmol/l.
- Zone IV – fosfagen, effort of supramaximal nature, lasting less than 10 seconds.

On the other hand, Faria[37] ascribe various oxygen uptake values (%VO_{2max}) to various intensity zones:

- Active rest (< 50% VO_{2max});
- Moderate aerobic zone (c. 50–70% VO_{2max});

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minants of VO(2) kinetics at high power outputs during a ramp exercise protocol, *Medicine and Science in Sports and Exercise*, 2002, vol. 34, no. 2, pp. 326–331; Hawley, Brouns, Jeukendrup, op. cit.

31 Lepretre, Foster, Koralsztein, Billat, op. cit.

32 Mujika, Padilla, Pyne, Busso, op. cit.

33 Myburgh K.H., Viljoen A., Tereblanche S., Plasma lactate concentrations for self-selected maximal effort lasting 1 h, *Medicine and Science in Sports and Exercise*, 2001, vol. 33, no. 1, pp. 152–156.

34 Hoogeveen A.R., Hoogsteen J., Schep G., The maximal lactate steady state in elite endurance athletes, *Japanese Journal of Physiology*, 1997, vol. 47, no. 5, pp. 481–485; Mujika I., Padilla S., Detraining: loss of training-induced physiological and performance adaptations. Part II: Long term insufficient training stimulus, *Sports Medicine*, 2000, vol. 30, no. 3, pp. 145–154.

35 Esteve-Lanao J., San Juan A.F., Earnest C.P., Foster C., Lucia A., How do endurance runners actually train? Relationship with competition performance, *Medicine and Science in Sports and Exercise*, 2005, vol. 37, no. 3, pp. 496–504.

36 Zatoń, op. cit.

37 Faria E.W., Recent advances in specific training for cycling, *International SportMed Journal*, 2009, vol. 10, no. 1, pp. 16–32.

– Intensive aerobic zone (c. 70–90% VO_{2max});
– Anaerobic zone (above anaerobic threshold).

Lactate threshold is determined mainly by: muscle buffer capacity, i.e. their capacity to absorb acidity; ability to transport lactate and hydrogen ions through sarcolemma muscle fibres (with the use of MCT1 and MCT4); lactate changes and finally, oxidation[38]. Great importance is also given to the ability to activate fatty acids oxidation as an energy source, even at very high intensity, in order to reduce lactate production[39].

Therefore, as a consequence of adaptation to training loads, swimmers should aim for lower acidity at the same (e.g. submaximal) effort. A positive symptom of athletes' endurance form is also the reaching anaerobic threshold at a higher value of oxygen consumption (higher %VO_{2max}) at effort. Such a training concept will result in a situation where swimmers will be able to increase contribution of the aerobic processes in energy acquisition. This will limit the production of lactate and its accumulation in the blood. In general terms, a well trained athlete may perform more work and maintain high power (85–90% VO_{2max}) over longer periods[40]. Analyzing the impact of training work on the point where metabolic thresholds occur, two variables that characterize effort must be noted: volume and intensity. It is crucial for less trained swimmers to practice longer but at low and moderate intensity. It decreases the frequency of heart contraction (systole) at the same submaximal work; increases activity and the number of mitochondrial enzymes and – to some extent – glicolytic enzymes, moving carbohydrate metabolism towards fatty acids. This is evidenced by the occurrence of a lower amount of discharged O_2 (VCO_2) and lower values of respiratory quotient (RQ) in response to an effort with the same external load[41]. As a result of higher level of aerobic oxidation, the lactate concentration in blood decreases at the same load level[42]. Data is available form the experiment by Esteve-Lanao et al.[43] that take into account impact of training in given intensity zones on sport performance. The researchers found a high correlation between the results achieved in a competition by a group of advanced cross-country skiers and the time they devoted to training in a low intensity zone. This coefficient increased as the distance increased (r = 0.79 for short distances of c. 4 km, r = 0.97 for long distances of 10 km). Improvement in the value of the aerobic threshold in response to a few-weeks training geared towards endurance, is postulated by more authors. This improvement is commonly related to positive changes in the value of oxygen uptake (VO_2) and improvement in VO_{2max}[44].

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38 Hawley, Brouns, Jeukendrup, op. cit.; Lucía, Rivero, Pérez, Serrano, Calbet, Santalla, Chicharro, op. cit.

39 Joyner, Coyle, op. cit.; Lucía, Rivero, Pérez, Serrano, Calbet, Santalla, Chicharro, op. cit.

40 Hawley, Brouns, Jeukendrup, op. cit.; Joyner, Coyle, op. cit.; Lucía, Rivero, Pérez, Serrano, Calbet, Santalla, Chicharro, op. cit.

41 Zatoń, op. cit.

42 Kubukeli, Noakes, Dennis, op. cit.; Putman C.T., Jones N.L., Heigenhauser J.F., Effects of short-term training on plasma acid-base balance during incremental exercise in man, *Journal of Physiology*, 2003, vol. 550, no. 2, pp. 585–603.

43 Esteve-Lanao, San Juan, Earnest, Foster, Lucia, op. cit.

44 Chtara, Chamari, Chaouachi, Chaouachi, Koubaa, Feki, Millet, Amri, op. cit.; Dressendorfer R.H., Petersen S.R., Moss Lovshin S.E., Hannon J.L., Lee S.F., Bell G.J., Performance

Swimmers should aim at improving work efficiency with high intensity over a longer period of time. That is why training programs should include time efforts exceeding 20 minutes with an intensity of c. 90% VO_{2max}. Thanks to this, athletes adjust to a long-lasting and intensive work. With an increase in oxygen uptake at respiratory thresholds (VT1, 2), and the improvement in VO_{2max}, W_{max} and performance at competitions, occurred among cross country skiers who did not perform better in standard training regimes. The changes only occurred as a result of doubling the contribution of intensive efforts (from 17% to 35% of the total time devoted to training) and lowering the low intensity training volume (by 22%).

As early as in 1992, Shephard and Astrand[45] described the analyzer of an Italian company, Cosmed, whose main characteristic were its small size. It can be used in conditions specific to a given movement (motor activity). Many studies show that[46] a detailed assessment of the physiological cost of work is both difficult and costly. Respiratory analyzers of minimal mass and the size of a small book, as well as various recorders of electric activity of the heart, may be used in almost all conditions. The problem is in comparing the effects of such studies, to be more precise – selection of such methods of gauging load and measuring the organism's activities, that would yield similar results in similar conditions. These conditions are related to movement which modifies organism's activity. One must remember that outside the laboratory, repetitiveness of environmental factors is low[47]. If we also take into account the fact that almost every work intensity, and the spatial course of work and amplitude, may be accompanied only partly by repetitive physiological reactions[48], then the above mentioned difficulties become apparent. Modern analyzers allow scientists too easily select the sampling frequency of the studied phenomenon. It is even possible to analize the composition of air in each expiration. In such cases one may empirically select optimal sequence of measurements over time.

However, it is extremely difficult to apply cardiovascular effort analyzers in water. We have already attempted to measure the impact of physical activity in water on the change of the organism's activities[49]. This time, however, Cosmed has offered to equip $K4b^2$ analyzer with Aqua Trainer, i.e. a set of mouthpieces and pipes that allowed the connection of the athlete exercising in water, to an ultra light respiratory analyzer. This has allowed the recording of any number of data in any given time. The analyzer was carried by a technician, on a long pole along the side of the pool, at the pace of the swimmer. Using this excellent analyzer, a measurement of the size (amplitude) of physiological reactions in two situations was attempted: while swimming and during laboratory work on an ergometer.

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enhancement with maintenance of resting immune status after intensified cycle training, *Clinical Journal of Sport Medicine*, 2002, vol. 12, no. 5, pp. 301–307; Hoogeveen, Hoogsteen, Schep, op. cit.

45 Shephard, Astrand, op. cit.

46 Zatoń, op. cit.; Kurz T., Science of sports training, Stadion Publishing Company, Island Pond, 1995, p. 85; Mc Ardle W.D., Katch F.J., Katch V.L., Exercise physiology: Energy, Nutrition and Human Performance, Williams and Wilkins, Philadelphia, 1991.

47 Mac Dougall J.D., Werner H.A., Greek H.J., Physiological testing of the high-performance athlete, Human Kinetics, Champaign, 1991.

48 Mc Ardle, Katch, Katch, op. cit.

49 Zatoń, op. cit.

It has been evidenced on many occasions that these activities generate various reactions[50]. The question is whether measuring with the use of dedicated appliances would allow us to make new discoveries.

Sports training requires very thorough monitoring of changes in the organism. Hence, the initiation of this experiment.

The aim of this work is to find reliable and repetitive ways of measuring certain features of organism changes in training conditions, in such a way that they could be a reliable basis for monitoring training effectiveness.

METHODS

Ten students of the University School of Physical Education in Wrocław (members of the swimming college team) were selected. These are healthy young individuals between the ages of 20 and 24. The findings on men have shown here. The average body mass of the men in question was 72.43 kg and they were on average, 181 cm tall.

The first stage of the experiment involved an endurance test performed on a Monarch 839 cycloergometer, programmed in such a way that, independently of the revolution frequency, the person performed a desired effort. The test was progressive and was continued until the person refused further action, or it was stopped when the oxygen uptake decreased (despite increase in load).

The load was changed at 3-minute intervals. The test was initiated after a warm up starting with the load of 50 W. Another 50 W were added every three minutes.

During this and other tests, the $K4b^2$ analyzer was used in order to determine the maximal oxygen uptake (VO_{2max}), the volume of carbon dioxide elimination (VCO_2), maximal respiratory quotient (RQ_{max}), maximal lung ventilation (VE_{max}) and maximal heart rate (HR_{max}). Additionally, in the third minute after finishing each work (test), an arterial blood sample was taken from the finger tip, to measure the maximal lactate concentration (LA).

A week after the test was completed all the persons were tested for endurance in water. The effort involved swimming the distance of 100 m at an average speed (after a warm up), at high and then at maximum speed. After swimming each distance the person rested passively for 10 minutes. During the swim every person carried an Aqua Trainer that was connected to the said analyzer. The same features were measured as in the previous test, in order to determine the highest values.

After a week's break (observing all rules described by Mac Dougall et al.[51]) another stage of the test was conducted.

Due to the fact that Aqua Trainer allows swimmers to perform turns only in the frontal plane (as the swimmers in question claimed), it imposed also further limitations: from limiting field of vision, to certain respiratory limitations. Therefore restitutional inertia of the features tested was used. This means that immediately after the effort was completed, respiratory activity, and the number of systoles remained at the effort level for a few, sometimes a few dozen, seconds. The delay in

[50] Counsilman J.E., La natation de competition, Vigot, Paris, 1986; Zatoń, op. cit.
[51] Mac Dougall, Werner, Greek, op. cit.

the analyses was only 0.14 seconds. One may assume, then that the measurements performed in such a way, would be characteristic for the last phase of the effort[52].

Mean arithmetic and standard deviation were measured, due to a small size of the group (despite its homogeneity in terms of endurance and technique) in order to assess the significance of differences between the same features tested in various trials, the Wilcoxon matched pair test was applied (available in Statistica suite). Differences at the level of $p < 0.05$ were considered significant.

RESULTS

The tests and measurements (Tab. 1) show that there are no substantial differences between the tested features (as the ergometer test and the test after swimming show); the phenomenon of the restitutional inertia was applied. The only significant differences in these tests were the after-effort lactate concentration (LA). Higher concentration was recorded after the swimming test.

All the tested features differ with respect to the ergometer test and test with the Aqua Trainer; in the latter all the tested features are lower (as in the test using inertia effort). In other words, using Aqua Trainer resulted in lower amplitude of effort reactions.

TABLE 1. Results of the ergometer test, Aqua Trainer, and with the use of inertia effort in the first stage of restitution.

Tests/parameters		VO_2 l min^{-1}	VCO_2 l min^{-1}	RQ VCO_2/VO_2	VE l min^{-1}	HR cycle/min	LA mmol · l^{-1}
Test		**4.35**	**4.41**	**1.01**	**150**	**189.65**	**9.43**$^{+}$
Ergometer	SD	0.75	0.82	0.04	29.42	8.71	1.12
Swimming Test w/aqutr.		**3.16***	**3.01***	**0.95***	**117.94***	**173.50***	**6.30***
	SD	0.75	0.81	0.04	28.73	19.44	1.12
Swimming test		4.39*	4.48*	1.02*	151.11*	191.30*	10.21*$^{+}$
only k4b2	SD	0.63	0.60	0.05	24.70	17.18	1.10

In bold – statistically significant differences ($p \leq 0.0500$) between the result of the tested feature in the ergometer test while swimming and during test w/aquatrainer

* shows statistically significant difference ($p \leq 0.0500$) between the result of the test in swimming w/aquatrainer and in the test done immediately after finishing swimming

\+ shows a statistically significant difference ($p \leq 0.05$) between the result of the ergometer test and the test done after swimming

DISCUSSION

Almost every researcher dealing with the physiology of effort knows that VO_{2max} can not be underestimated. Studies of this particular feature, in the environment where it is used, is of primary importance. Due to this fact sport disci-

[52] Mc Ardle, Katch, Katch, op. cit.

plines are trained by the people with different muscle characteristics (with respect to structure or physiological features). At the same time those people can run, swim or cycle for long periods of time. Swimming is known to be, to a large extent, determined by this particular feature[53]. Its further study may be of strategic importance. In the course of the experiment it turned out that there were no statistically significant differences between VO_{2max} in the ergometer in water, provided that there was full freedom for discharging power. Limitations imposed by the Aqua Trainer make this complicated method less useful in comparison to swimming with no constraints; only then can we control it in the least limited moment of movement[54]. However, although it may be further evidenced in more experiments, effort studies with the use of the Aqua Trainer will be the proper method for people who swim recreationally, or for rehabilitation reasons. Gayda et al.[55] reached similar conclusions.

Another interesting result of the study was that the highest lactate concentration was determined after maximum intensity swimming, and not after the ergometer test. This undermines certain assumptions[56], that the water environment does not leave room for the large contribution of anaerobic processes (due to specific resistance generating limited power in muscles and also due to the fact that the position of the swimmer is horizontal – hence allowing for economization of movements). Other researchers dealing with the impact of endurance training on organism share this assumption[57]. It is clear that 10 $mmol \cdot l^{-1}$ of plasma (such was average lactate concentration) is not exceptional in sport[58], however, this may be an interesting adaptive change resulting from long lasting sports training. Perhaps a group of people with other adaptive strategies has been identified…

CONCLUSIONS

A similar level of most physiological features between the results of ergometer test and in swimming "with no constraints" test has been determined; hence this method better meets the needs of close control of training effects in swimming.

The Aqua Trainer may be useful in recreational swimmers, where technique constraints need not have a great impact on effort reactions amplitude.

Perhaps systematic recording of lactate concentration in plasma in training may allow the determine of the impact of swimming on development of anaerobic endurance, and its contribution to sport performance enhancement.

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[53] Counsilman, op. cit.; Zatoń, op. cit.

[54] Zatoń M., Zatoń K., Klarowicz A., Using Cosmed K4b^2 Analyzer to Control Load in a Swimming Training, *Polish Journal of Environmental Studies*, 2006, vol. 15, no. 2B, part V, pp. 1720–1722.

[55] Gayda M., Bosquet L., Juneau M., Guiraud T., Lambert J., Nigam A., Comparison of gas exchange data using the Aquatrainer system and the facemask with Cosmed K4b2 during exercise in healthy subjects, *European Journal of Applied Physiology*, 2010, no. 109, pp. 191–199.

[56] Pelayo P., Maillard D., Rozier D., Chollet D., De la natation au collège et au lycée, Editions Revue EPS, Paris, 1999.

[57] Hoogeveen, Hoogsteen, Schep, op. cit.

[58] Mc Ardle, Katch, Katch, op. cit.

≈ SCIENCE IN SWIMMING III, 2011, 72–81

Efficiency of kinematics parameters in the 100 m individual medley test among 14-year old swimmers from Championship Schools in Kraków

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INTRODUCTION

Swimming is a discipline in which the sporting challenge is an individual competition, based on the principles of rivalry, with a focus on perfection, which is played out in standard conditions, and which may have the characteristics of a confrontation, with the participation of one or many entities, culminating in an objectively quantifiable result. An observation of the development of the sport of swimming in the world, shows different ways to bring male and female swimmers to championship level. The continued increase of records and successes in the international sporting arena will depend, to a decisive extent, on the expected trends in the development of training methodology, the effective combining of theory with practice, creative exploration and bold experimentation initiatives[1].

Every sportsperson participating in a sports competition at the highest level, no matter what discipline he cultivates, should be characterized by the optimal physical, motor, functional, technical, psychological and tactical features. When referring to competitive swimming we could say that, among the factors which guarantee obtaining of the optimal result, is an adequate level of technical preparation, including kinematic parameters[2]. Such kinematic volumes as stroke rate and stroke length, and the average swimming speed and the duration of the transition from start to swimming, determine the time of the swimming of a certain distance. The final sports outcome is also determined by the course and duration of turn and finish. Obtaining figures on these elements provides the basis to analyze the structure of the swimming race and swimming techniques. Known methods to obtain data on these volumes are:

– biomechanical method of observation of swimming competitions,

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1 Ważny Z., Theory of sports training [in Polish], AWF, Warszawa, 1989.

2 Aloes F., Cunha P., Gomes-Pereira J., Kinematics changes with inspiratory actions in butterfly swimming, [in:] Keskinen K.L., Komi P.V., Hollander A.P., (eds.), Biomechanics and Medicine in Swimming VIII, Gummerus Printing, Jyväskylä, 1998, pp. 256–260; Dybińska E., Kucia-Czyszczoń K., Haljand R., Tactical swimming race strategy based on Haljand's method of forecasting sports result [in Polish], *Sporty Wodne i Ratownictwo*, 2008, vol. 1, pp. 23–29.

– examination of components of the swimming race;
– examinations with the use computer methods on a swimming technique[3].

Basic assumptions of each of these methods assume that the analysis involves: the sports result as the main objective of the race, the basic kinematic volumes and the possibilities of using obtained data in practice.

Typically, as it is the case in the first of the methods mentioned, in order to collect data for analysis of the swimming race, one measures fractional duration times of duration, duration itself, as well as the frequency of motor cycles in the following areas: start, turn, finish, and "pure swimming". Obtaining such data as sroke rate, stroke length and the average swimming speed in specific sections, allows learning the volume and observing the changes of the basic parameters of swimming techniques, in selected sections of the distance[4]. An appropriate interpretation of the results leads to the proper diagnosis and forecast of swimming results. Such data also provide information on competitive type situations, which can be simulated during training, by creating specific simulators for a race using partial results, frequency and stroke length. They also allow individual comparison of the effectiveness and relapse-off against the model standards.

Over a distance of 100 m in the individual medley the following components[5] were divided:

– 100 IM Result;
– Start time and speed 15 m (T-start, V-start);
– Swim time and speed over first 25 m (T "pure swimming" V "pure swimming");
– Swim time and speed over second 25 m (T "pure swimming" V "pure swimming");
– Swim time and speed over third 25 m (T "pure swimming" V "pure swimming");
– Swim time and speed over last 25 m (T "pure swimming" V "pure swimming");
– Stroke lenght (SL) in selected 25 m sections of the 100 m individual medley;
– Stroke rate (SR) in selected 25 m sections of the 100 m individual medley;
– Speed (V) in selected 25 m sections of the 100 m individual medley;
– Index in selected 25 m sections of the 100 m individual medley;
– Turn time and speed in first 25 m (T turn I, V turn I);
– Turn time and speed in second 25 m (T turn II, V turn II);
– Turn time and speed in last 25 m (T turn III, V turn III);
– Finishing time and speed in last 5 m (T finish, V finish).

The importance of basic components of the race varies with the length of the distance. A survey conducted by the authors[6] clearly indicates that there are signifi-

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3 Bartkowiak E., Swimming Sport [in Polish], COS, Warszawa, 1999.

4 Ibid.

5 Platonov W.N., Wojciechowski C.M., Swimming training top level swimmers [in Polish], Fizkultura and Sport, Moscow, 1985; www.swim.ee – website of Rein Hailand.

6 Opyrchał C., Płatek Ł., Karpiński R., Analysis of Otylia Jedrzejczak's swimming in the 200 m butterfly stroke race at the World Swimming Championships in Barcelona, [in:] Mynarski W., Ślężyński J. (eds.), Effects of Education in Physical Culture [in Polish], AWF, Katowice, 2005, pp. 291–299; Dybińska E., Haljand R., Spatiotemporal (kinematic) properties of the finalists of European Swimming Championships in butterfly stroke Trieste 2005, *Human Movement*,

cant relationships between the sports results obtained in a given distance and volumes of kinematic parameters in different zones, the components of the swimming race.

The analysis of the swimming race made against its structure and component parameter values, which may affect the obtained result, was the inspiration for the authors to make detailed observations on this issue.

The primary aim of this paper was to investigate for relationships between the level of selected kinematic parameters volumes and obtained sports results in 100 m individual medley (IM) by 14-year old female and male swimmers.

Research questions were:

1. What was the sports level of 14-year old swimmers who were under observation?
2. To what extent were morphological parameters correlate with the efficiency of swimming of the swimmers examined?
3. How did the volumes of the kinematic parameters for each of the 25 m sections of the test in the 100 m IM develop, and to what extent could they be important in the outcome of the sports result?

METHODS

The research was conducted at the 25-metre swimming pool of the University School of Physical Education in Kraków in the winter 2009. 16 swimmers at the age of 14, including 8 girls and 8 boys – all of them swimmers of the Championship School in Kraków, participated in it. The primary method of research was direct and indirect observation. The specific efficiency of the examined was assessed on the basis of the 100 m individual medley test result and the measurements of various sections of distance of 25 m. The volumes of selected kinematic parameters were defined, owing to the recordings obtained by using the multi-camera swimming technique registration system (Fig. 1), and recordings were carried out by a team of researchers from the Swimming Techniques Laboratory[7].

The multi-camera motion technique analysis system allowed for a detailed record of the movement technique of swimmers in the following areas:

2007, vol. 8, no. 2, pp. 104–111; Dybińska E., The assessment of the efficiency of swimming in relation to selected indicators of somatic and motor skills of 12-year-old female and male swimmers from MKS “Jordan” in Krakow, University of Szczecin, Albatros, Szczecin, 2006, pp. 115–122; Kucia-Czyszczoń K., Dybińska E., Co-ordination abilities and sports result of 11–12-year-old swimmers, [in:] Zatoń K., Jaszczak M. (eds.), Science in Swimming II, AWF, Wrocław, 2008, pp. 69–78; Dybińska E., Haljand R., Analysis of starts of the world champion Otylia Jedrzejczak in 100 and 200 m distances in butterfly stroke on the European Swimming Championships in Debrecen (2007), [in:] Umiastowska D. (ed.), Motor activity in people of all ages, Albatros, Szczecin, 2009, pp. 233–246; Kucia-Czyszczoń K., Dybińska E., The use of multi-camera image recording system as a tool for the analysis of swimming techniques in swimming training [in Polish], *Sporty Wodne i Ratownictwo*, 2009, vol. 1, pp. 20–30.

7 www.l-p-t.pl – website of Laboratory of Swimming Technique.

FIGURE 1. Multi-camera swimming technique registration system (www.l-p-t.pl – website of Laboratory of Swimming Technique)

- overwater side view – the entire distance of 100 m;
- underwater side view – the entire distance of 100 m;
- underwater view – the frontal plane, relapse elements of the distance of 25, 50 and 75 m;
- covered;
- overwater view – frontal plane (top view) of the total distance of 100 m.

Through the use of the modern swimming technique recording system for swimmers (with 5 cameras – 3 underwater and 2 overwater) and the possibility of multiple recording and playback in slow motion playback or image retention (using stop-frame), a detailed analysis of the structure and trajectory of movement over a distance of 100 m in the IM, allows for the accurate determination of the parameters for research.

Each individually subject examined covered the distance of 100 in the IM, with a start up speed, on the appointed track, doing the start from the command issued by the starter. After the swimming and registering of the trial, each technique was analyzed individually in terms of structure and motion trajectory.

Detailed observations were made of the following kinematic parameters, which were distinguished in the structure of the race swum (Fig. 2):

- time and speed off – were measured for the first 15 m of the distance, from the signal till the moment of passing the designated point at 15 m of the swimming pool;
- time and speed of turn for 25, 50 and 75 m – were measured in the range of 5 m from the relapse wall to 15 m after the turn;

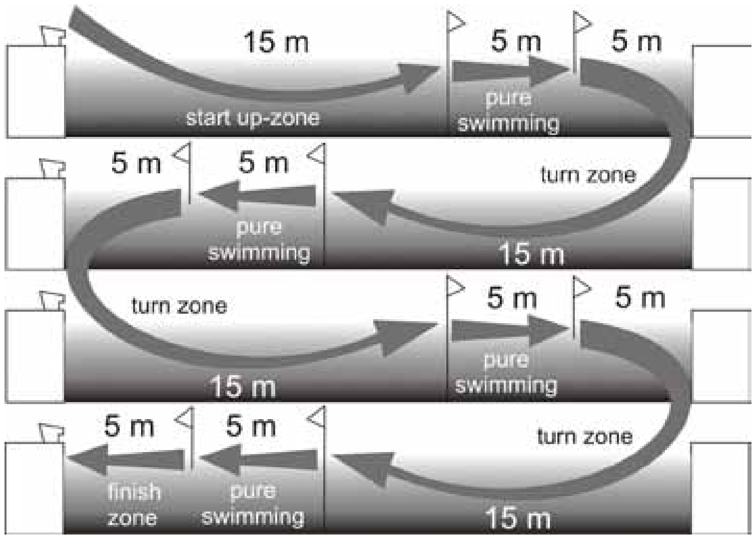

FIGURE 2. Zones of measurement of kinematic parameters

– time and speed of the finish – were designated on the last 5 m of the distance, before the end wall of the swimming pool;
– time and speed of "pure swimming" – were recorded on a particular stretch of distance, with the exception of take-off, relapse and finish zones.

Stroke length, stroke rate, swimming speed and swimming efficiency ratio – (SE index): volumes of those kinematic parameters were calculated according to formulas given by Bartkowiak[8].

In order to assess the level of somatic development of the examined measurements of morphological parameters: height, body mass, FAT mass and arms span were examined.

In looking for relationships between variables taken into account, the authors used Pearson's linear correlation by calculating the 'r' correlation coefficient.

RESULTS

In formulating the general characteristics of the test group of 14-year old students of the Championship Schools in Kraków, it was found that the length of the sport experience of female and male swimmers ranged from 3.5 to 6 years. In the winter 2008/2009 the respondents obtained the results which did not qualify all of them for achieving the desired sports level. 3 from 8 contestants (representing 37.5% of girls) and 4 out of 8 swimmers (which accounted for 50% of boys) obtained the second sports class in their age category in the 100 m IM competition (based on the minimum set by the Polish Swimming Association defined for girls: 1:16.44 min, and 1:11.60 min for boys).

[8] Bartkowiak E., Swimming Sport [in Polish], 2nd ed., COS, Warszawa, 2008.

SWIMMING EFFICIENCY OF THE SUBJECTS

Statistical values of the results of 100 m IM examined boys and girls are presented in Tab. 1. The evolution of the average values obtained by the subjects (girls and boys) in the 100 m individual medley competition, at the specific 25 m sections of the distance (butterfly, backstroke, breaststroke and freestyle) are shown in Tab. 2 and 3.

TABLE 1. Statistical values of the result from the 100 m IM of the examined girls and boys

Gender	100 m individual medley (s)					
	$\bar{x}$	SD	min	max	R	V%
Girls	78.92	5.45	68.80	84.00	15.2	6.90
Boys	73.11	5.90	66.35	80.85	14.5	8.07

TABLE 2. Average values obtained by the subjects in the competition, 100 m IM at the various sections of 25 m distance

Gender	25 m butterfly (s)		25 m backstroke (s)		25 m breaststroke (s)		25 m freestyle (s)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Girls	16.84	1.64	20.27	1.57	23.16	1.46	18.65	1.10
Boys	14.98	1.24	18.26	1.64	22.29	1.75	17.58	1.54

SOMATIC SIZE CHARACTERISTICS OF RESPONDENTS

When assessing the level of somatic development of the respondents authors referred to the main results of the morphological characteristics of boys and girls to peers of the population “Child of Kraków”[9].

The subject 14-year old swimmers, both boys and girls (Tab. 3) were characterized by a higher parameters of height and body weight (Tab. 4) than the population of their peers, i.e. the “Child of Kraków”.

TABLE 3. Average values of body height of the subjects in relation to the “Child of Kraków”

Gender	Body height (cm)						“Child of Kraków”	
	$\bar{x}$	SD	min	max	R	V%	$\bar{x}$	SD
Girls	164.66	6.24	159.9	178.7	18.8	3.78	161.6	6.05
Boys	167.78	4.83	160.0	173.2	13.2	2.87	165.7	8.29

TABLE 4. The average body weight of the subjects in relation to the “Child of Kraków”

Gender	Weight (kg)						“Child of Kraków”	
	$\bar{x}$	SD	min	max	R	V%	$\bar{x}$	SD
Girls	51.58	5.40	42.7	58.9	16.2	10.46	51.0	9.41
Boys	55.72	7.73	46.6	67.2	20.6	13.87	52.8	10.45

[9] Chrzanowska M., Gołąb S. (ed.), Child of Kraków 2000 [in Polish], *Studia i Monografie AWF w Krakowie*, 2003, no. 22.

The average values of the FAT mass (fat mass) of the respondents, i.e. 14-year old female swimmers (Tab. 5) were significantly higher (13.54%) than their male peers (4.67%), but much more inter-individual variation than among the female swimmers was observed among the swimmers in the area of this parameter, as proved by the much higher values of the coefficient of variation.

TABLE 5. The average values of FAT mass (the level of body fat) of the subjects

Gender	FAT mass (%)					
	$\bar{x}$	SD	min	max	R	V%
Girls	13.54	5.72	2.9	21.6	18.7	42.24
Boys	4.67	3.15	2.4	10.7	8.3	67.45

TABLE 6. The average values of arms span of the subjects

Gender	Arms span (cm)					
	$\bar{x}$	SD	min	max	R	V%
Girls	167.20	9.53	157.2	185.5	28.3	5.69
Boys	176.08	8.26	163	184	21	4.69

VOLUMES OF KINEMATIC PARAMETERS OF THE 14-YEAR OLD FEMALE AND MALE SUBJECTS

Progression of the volumes of the kinematic parameters in the 100 m IM test in each distance zone – start, turns, finish and "pure" swimming of 14-year old girls and boys are shown in Tab. 7, 8 and 9.

TABLE 7. Statistical values of kinematic parameters in the 100 m IM

Gender	T-start (s)		V-start (m/s)		T finish (s)		V finish (m/s)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Girls	8.70	0.96	1.75	0.21	4.11	0.16	1.22	0.05
Boys	7.73	0.64	1.95	0.16	3.93	0.25	1.28	0.08

TABLE 8. Statistical values of kinematic parameters in the 100 m IM

Gender	SL (m)		SR (cycle/min)		V (m/s)		Index	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Girls	1.80	0.21	42.63	3.58	1.27	0.09	2.31	0.44
Boys	1.83	0.14	45.00	1.67	1.38	0.11	2.52	0.38

TABLE 9. Statistical values of kinematic parameters in the 100 m IM

Gender	T "pure" swimming (s)		V "pure" swimming (m/s)		I turn T T		II turn T T		III turn T T	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Girls	16.6	1.00	1.21	0.07	15.42	1.36	18.32	1.30	15.75	0.97
Boys	15.44	1.40	1.30	0.11	13.75	1.18	17.33	1.56	14.81	1.12

Analyzing the average values of the subjects variables (Tab. 7–9), it is noted that the 14-year old boys have obtained higher values than girls in all the kinematic parameters in the 100 m IM test. Likewise, larger inter-individual variation in such parameters as start time and speed, stroke length, swimming, attendance and time of turn, were observed among female swimmers than in boys.

CORRELATIONS BETWEEN VARIABLES TAKEN INTO ACCOUNT

In order to answer the fundamental research questions – fundamental analyses on the relationship between variables taken into account have been made.

In analyzing the relationships between swimming skills and the morphological characteristics (Tab. 10), it should be noted that dependences ($p > 0.05$) between

TABLE 10. The values of the (r) Pearson linear correlation coefficients between the morphological characteristics and swimming efficiency of the respondents

Gender	Body height and the 100 m individual medley	Body mass and the 100 m individual medley	FAT mass and the 100 m individual medley	Arms span and the 100 m individual medley
Girls	–0.79*	–0.70*	–0.46	–0.75*
Boys	–0.81**	–0.58	0.42	–0.80**

* p > 0.05, ** p > 0.01

TABLE 11. The values of the (r) Pearson's linear correlation coefficients between selected kinematic parameters

Selected kinematic parameters	25 m butterfly		25 m backstroke		25 m breststroke		25 m freestyle	
	girls	boys	girls	boys	girls	boys	girls	boys
T-start	0.92**	0.97**						
V-start	–0.92**	–0.96**						
SL (m)	–0.74*	–0.88**	– 0.57	–0.82*	– 0.58	–0.83*	–0.53	–0.46
SR (cycle/min)	0.04	0.37	–0.11	–0.34	–0.43	–0.27	0.071	–0.48
V(m/s)	–0.99**	–0.99**	–0.99**	–0.99**	–0.99**	–0.99**	–0.99**	–0.99**
SE Index	–0.90**	–0.94**	–0.82*	–0.92**	–0.81*	–0.93**	–0.77*	–0.80*
T "pure swimming"	0.95**	0.92**	0.88**	0.93**	0.68*	0.98**	0.74*	0.91**
V "pure swimming"	–0.95**	–0.92**	–0.89**	–0.92**	–0.69*	–0.99**	–0.76*	–0.89*
T turn I	0.94**	0.96**						
V turn I	–0.93**	–0.95**						
T turn II			0.91**	0.98**				
V turn II			–0.90**	–0.96**				
T turn III					0.95**	0.93**		
V turn III				–0.95**	–0.95**	–0.92**		
T finish							0.92**	0.87*
V finish							–0.92**	–0.87*

* p > 0.05, ** p > 0.01

the test result in 100 m medley and the body height among girls and boys, as well as arms span and body weight, were only reported in the swimmers.

Volumes of kinematic parameters of the examined 14-year old female and male swimmers (Tab. 11) such as start time and start speed, swimming speed, duration and turn, very highly correlated (both girls and boys) with the result obtained on each of the 25 m distances covered in butterfly, backstroke, breaststroke and freestyle that are the components of the 100 m IM. Parameters of time and speed of "pure" swimming and swimming efficiency ratio (index) also showed high correlations, especially in boys ($p > 0.01$), while in girls at a slightly lower level ($p > 0.05$). By contrast, when it came to the freestyle stroke, the stroke rate (frequency), among both girls and boys in all component sections of the distance, and the swimming stroke length in most cases, did not show significant relationships with the sports result obtained in the specific sections of the distance. The swimming stroke length correlated with the result obtained in the 25 m sections of the butterfly, backstroke, and the breaststroke ($p > 0.05$, $p > 0.01$) in boys.

DISCUSSION

The primary aim of this paper was to investigate the relationships between the level of selected kinematic parameter volumes and obtained sports results over in the 100 m individual medley (IM) by 14-year old female and male swimmers.

Insightful analysis of selected kinematic parameters for each of 25 m sections of the 100 m individual medley test allow the statement that in most cases, both among girls and boys, those variables are very highly or highly correlated with the sports result. The stroke rate (frequency), and in three cases among girls and in one among boys – stroke length – were the least important parameters for obtaining swimming performance in both sexes. It is believed that these variables are the two compatible kinematic parameters, particularly co-ordinated with each other, and largely subject to the individual predispositions of individual swimmers. A swimmers should master stroke length, in order to keep the optimal volumes of swimming and should maintain the highest frequency of motor cycles while covering the distance. The results obtained allow the suggesting that 14-year old swimmers, especially young girls, do not yet have such a skill and confirm the results of other authors[10].

It seems that the 100 m individual medley and insightful observation of kinematic parameters, including components of the swimming race: the start zone, the turn zones, finish zone and the zone of "pure swimming", are a test giving in-

[10] Pelayo P., Sidney M., Kherif T., Chollet D., Tourny C., Stroking characteristics in freestyle swimming and relationships with anthropometric characteristics, *Journal of Applied Biomechanics*, 1996, no. 12, pp. 197–206; Pelayo P., Wille F., Sidney M., Berthoin S., Tourny C., Swimming performances and stoking parameters in non skilled grammar school pupils, *Journal of Sports Medicine and Physical Fitness*, 1997, no. 37, pp. 187–193; Pelayo P., Dekerle J., Sidney M., Specific indirect measurement of aerobic endurance in swimming and stroking parameters, [in:] Zatoń K., Rejman M. (eds.) Science in Swimming I, AWF, Wrocław, 2007, pp. 69–75.

formation on the versatility of style of a given swimmer, especially one being in the stage of specialist preparation.

CONCLUSIONS

The basis of detailed research results the following generalization was formulated:

1. 14-year old swimmers, students of Championship School in Kraków, presented an average level of ability, because only half of them (and in the girls even slightly less) presented in this age category, second class sport.
2. Tested 14-year old adolescents (both girls and boys) were characterized in terms of the level of somatic development parameters by height, weight and arm span, than the compared population of a "Child of Kraków".
3. The selected morphological parameters showed, in most a significant correlation in boys and girls (in most cases examined) with the efficiency of compound swimming, as expressed in the result of the 100 m individual medley test.
4. The vast majority of kinematic parameters included, showed a significant correlation (at a high level) with the efficiency of a swimming in studied swimmers, presented on the sub-sections of the 100 m individual medley.
5. Modern equipment in the form of the multi-camera swimming technique registration system, used in the study by the Laboratory of Swimming Techniques, helped us make detailed measurements of the kinematic parameters over the swimming distance (100 m individual medley) taken into account, so the system has proved to be an effective tool for this type of observation.
6. Detailed observation of the structure of a swimming race, for analysis of the component parameters at each stage of sports training, can be a valuable clue for the diagnosis and forecasts of a sports result. Which can in turn, foster the efficiency of the training process.

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Quantitative criterion of swimming techniques using multi-camera registration system on the example of individual medley, among 13–14-year old girls

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INTRODUCTION

The dynamics of performance in professional sport requires a systematic improvement of the training process. Such activities should also include optimizing the training of children and youth in these disciplines, where an early specialization operates. In swimming, with its specific environment, children can obtain good results relatively quickly, appropriate to their physical capabilities. What is more important here, however, are the actions aimed at teaching children good habits connected with movement, whose formation at a young age is important because of the plasticity of the nervous system. Habits are formed, and they remain, based on an individual's peculiar style of swimming technique. What is referred to as the "player's career," and is perfected and adapted to changing morphological and functional conditions of a specific athlete. In competitive sport, where fractions of a second often determine success, coaches and players are looking for a more efficient means of increasing the effectiveness of the management of the training process[1]. One method of monitoring the training of swimmers is the analysis of swimming race divided into its structure and component values, so you can assess the level of training in terms of player movement techniques[2]. According to Czabański[3], in sports techniques, the gradation of errors should be distinguished. The error in technique of operations performed is the deviation from the intended action. However, the degree of variation is often very different, therefore, one has to distinguish three categories of errors and properly label them:

- Error in technique – function through exercise is different from the intended movement. It is an activity in which there are elements that are completely incompatible with the anticipated program of action.
- In technology is defined herein as behavior, which is relatively consistent with the intention, yet is somewhat to sometimes considerably simplified. It

1 Broker J.P., Craweley J.D., Advanced sport Technologies: Enhancing Olympic Performance, [in:] Blackwell J.R. (ed.), Proceedings of the XIXth ISBS Symposium, San Francisco, 2001, pp. 323–327.
2 Maglischo E.W., Swimming even faster, Mayfield Publishing, Mountain View, 2003.
3 Czabański B., Selected issues of learning and teaching sports technique [in Polish], AWF, Wrocław, 1991.

is characterized by a lack of certain elementary movements, or even motor acts, in the whole algorithm of technique.
– Deviation from techniques are the result of individual differences in structure and functional capacity of those performing the task. Most often they concern a difference in the movements in relation to a reference technique. They are determined on the basis of the average relating to many very good athletes. Deviations from the techniques are neither the changes in the algorithm of movements, nor omissions in the locomotor activity. They are simply differences that arise from the different structure of a universal pattern of individual characteristics of a practicing person[4].

Thus, the inspiration to engage the subject was to seek a substantive criterion of competitive swimming techniques, using a multi-camera registration system on a sample of movement analysis, of a 100 m individual medley. This test has been chosen in such a way as to allow a versatility of style within the female swimmers surveyed.

The primary aim of this work was to search for the relationship between the level of technical training for female athletes, and results over a distance of a 100 m individual medley, obtained by 13–14 year old girl swimmers from the School of Sports Championship in Kraków. Research questions were formulated as follows:

1. How developed is the reaction time to a distance of 100 m individual medley by the 13–14 year old swimmers surveyed, in relation to the response time obtained by a comparative peer population at competitions?
2. What was level of swimming technique (its constituent elements) among 13–14 year old female contestants in an all-embracing competition – which is a distance of 100 m in the individual medley – and what could have an impact on the outcome obtained in this race?
3. What kind of correlation between kinematic parameters and technical efficiency in the four strokes, in a 100 m IM, were observed?

METHODS

The study was conducted on 7–8 February 2009, at the swimming pool of AWF Kraków. The study group consisted of 30 female contestants from Małopolska district, having 4–6 years of competitive experience. The tests took place during the transitional period, after the main starts, at the Winter Championships of Polish 14-year olds.

The observations were made by observation with the collaboration of researchers from the Laboratory of Swimming Techniques[5]. Registration of individual swimming techniques was performed using a multi-camera image registration system. In the study conducted, female swimmers were to swim the 100 m individual medley with a boot speed. Each contestant performed the test individually, on a separately marked track, in accordance with the rules of FINA, i.e. the existing start-up, recurrences and finish. The distance traversed by the female swimmers

[4] Ibid.
[5] www.l-p-t.pl – website of Laboratory of Swimming Technique.

was recorded on a multi-camera system which recorded swimming techniques and consisted of the following devices:

- a sliding platform on which a system of five cameras was installed: four aquatica cameras and one underwater camera; image recording speed was 25 frames per second;
- one-meter long poles (as tags) mounted on rail lines along the entire length of the swimming pool (at 1 meter from the wall starting from recurrent pool), with special distinguishing of the longer poles at the 5th and 20th meter of the swimming pool;
- additional (sixth) underwater camera recording the image in the exercise of recurrences – mounted on the recurrent wall (on the opposite side of the upright boot);
- a multi-camera motion analysis system of the movement technique allowed for a detailed recording of movement techniques of the female athletes tested, in the following areas:
  - side view above the water surface – recording the entire 100 m distance;
  - underwater from side view – the entire recording 100 m distance;
  - underwater view – recording in frontal plane, components of relapse in sections 25 and 75 m of the distance covered;
  - above-the-water view – recording the frontal plane (top view) of the entire 100 m distance[6].

Owing to the obtained recordings (in a digital system) and the possibility of release or use of the freeze-frame image, a detailed analysis and evaluation of various techniques for swimming (a 100 m individual medley composed of – butterfly, backstroke, breaststroke and freestyle) presented by the swimmers, in terms of correctness of structure and motion trajectory, was made. Evaluation of movement techniques was carried out by two independent experts, using subjective methods, with a fair knowledge of swimming techniques being evaluated, and who relied on the movement patterns contained in swimming techniques cards[7]. These cards were designed by the authors of the work, on the basis of a model of swimming techniques, proposed by Prof. Rein Hailand[8], for specific techniques within alternating styles, with relapses between the styles. This paper therefore, attempts to unite the qualitative and quantitative analysis. Such analysis falls under the concept of in-depth qualitative analysis[9].

In assessing the motion technique the following scores were introduced:

1. For each of correctly executed element of movement techniques, the contestant received 1 point (+1).

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6 Kucia-Czyszczoń K., Dybińska E., Application of Multi-camera system of image registration in swimming training as a tool for analysis of the parameters of swimming technique [in Polish], *Sporty Wodne i Ratownictwo*, 2009, vol. 1, pp. 20–30.

7 Kucia-Czyszczoń K., Dybińska E., Analysis of kinematic parameters in the freestroke of the player Jan Smoliński from UKP ‘Unia Oświęcim’ on the basis of a multi-camera swimming techniques registration system, [in:] Rutkowska E. (ed.), Wellness and Success in Sport, Neurocentrum, Lublin, 2009, pp. 73–89.

8 www.swim.ee

9 Król H., Criteria of selection and evaluation of exercises perfecting the sports technique, AWF, Katowice, 2003.

2. For errors in technique of motion 1 point was deducted (–1).
3. For deficiencies or deviations from the given element of movement techniques the contestant received 0 points.

Thus, taking into account both the structure of the various swimming techniques, and components of the distance, the following scoring criteria were used (point index of movement technique – points):

- Start jump – 0–10 pts.
- Driving work of the arms and legs – butterfly "pure swimming" 0–9 pts.
- Turn of the butterfly to the backstroke – 0–8 pts.
- Driving work of the arms and legs – backstroke "pure swimming" 0–12 pts.
- Turn of the backstroke to the breaststroke – 28 pts.
- Driving work of the arms and legs – breaststroke "pure swimming" 0–15 pts.
- Turn of backstroke to freestyle – 8 pts.
- Driving work of the arms and legs – free "pure swimming" 0–13 pts.
- Finish 0–3 pts.

Total points received by individual female swimmers, for the above mentioned elements of swimming techniques evaluated, could be contained in the range 0–113. Differentiation of the maximum value in the assessment of swimming technique, was based on the fact card designed for this assessment. Each segment considered is composed of different amounts of assessed elements, while of course, taking into account both the structure of the various techniques and components of swimming distance.

The multi-camera system of recording swimming techniques was supplemented by an electronic time measurement for each 25 m segment (for the 100 m IM). In addition, an overlay page was installed on the starting platform, which allowed measurement of the speed of the start reaction time of the swimmers.

The speed response time results obtained were compared with the results (owing to the database developed by the Polish Swimmers Union www.omegatiming.pl) for this parameter, obtained by the female swimmers tested in the 2009 for Polish Junior Winter Championships for 13–14-year old, which took place on a 25-meter swimming pool (where electronic measurement of the speed of reaction time was used).

In addition, the studies measured the following kinematic parameters:

1. Time of "pure swimming" on a particular 25 m stretch; the average swimming speed was recorded (average V) at individual sections of the distance, measured with the exception of start zones, recurrence and finish.
2. Swimming speed (V) obtained at different distances of 25 m.
3. Stroke length (SL) and stroke rate (SR) obtained at different distances of 25 m.
4. Index The efficiency of swimming (SE index) – was calculated using the following formula:

$$SE\ INDEX = SL\ (\mathrm{m}) \cdot V\ (\mathrm{m/s}),$$

where:

SE INDEX – index of the effectiveness of swimming;
SL (m) – the average length of the step pool;
V (m/s) – average speed over a distance swimming.

The size of the kinematic parameters were calculated according to the formulas given by Bartkowiak[10].

[10] Bartkowiak E., Swimming Sport [in Polish], COS, Warszawa, 1999.

Empirical material collected using the multi-camera method for registering movement techniques, enabled biomechanical assessment of the swimming techniques of the female contestants undergoing the test. The results were presented using basic statistical characteristics. Detailed analysis and studies of material obtained through the use of multi-camera system, for the registration of the motion techniques, were made by using Virtual-Dub computer software. Looking for relationships between qualitative variables taken into account, the authors used Spearman's correlation, but when considering the dependence of the quantitative variables they used Pearson's correlation[11].

All statistical calculations were made using Statistica 7 (StatSoft Poland, 2008) at the level of statistical significance determined at $p < 0.05$.

RESULTS

Taking into consideration the results of the studies conducted, the primary subject to detailed analysis were the parameters of the start response time of 13–14 year old swimmers.

Analysing the average values and standard deviations (Tab. 1) of the parameter, that being the start reaction time of swimmers, it can be seen that these variable results obtained in the test results deviate from the parameters obtained from the larger sample from the competitions. These differences are not large, and are probably due to the low numbers in the study sample, in relation to the sample from the competition. Start response time correlations of those tested (Tab. 1) with result in the 100 m individual medley, both in competition and in relation to the studies, proved to be statistically insignificant.

TABLE 1. The average and standard deviations of reaction time and the result in the 100 m IM from the collected studies of 13–14-year old swimmers, and the correlations between these variables

Parameters	100 medley $\bar{x}$ (s)	SD	start reaction time $\bar{x}$ (s)	SD	Pearson correlation
Competition	75.66	4.42	0.86	0.087	0.298
Test	81.76	6.82	0.91	0.058	–0.171

A detailed analysis of startup reaction times of the swimmers in the 100 m individual medley, obtained during the test (Fig. 1), compared with the results collected during sporting events, indicates that the data are distributed normally, as the designated average within standard deviation (in such an amount of data) with a high probability corresponds to the comparator (from the competition) in the age groups (Tab. 2).

Subsequent analysis has been made concerning the correlation between kinematic values obtained by the tested swimmers, at each 25 m sections of 100 m individual medley, and the evaluation of the swimming techniques expressed in point values (point-evaluation indicator of the swimming techniques PKT).

[11] Ryguła I., Research process in sports sciences [in Polish], AWF, Katowice, 2004.

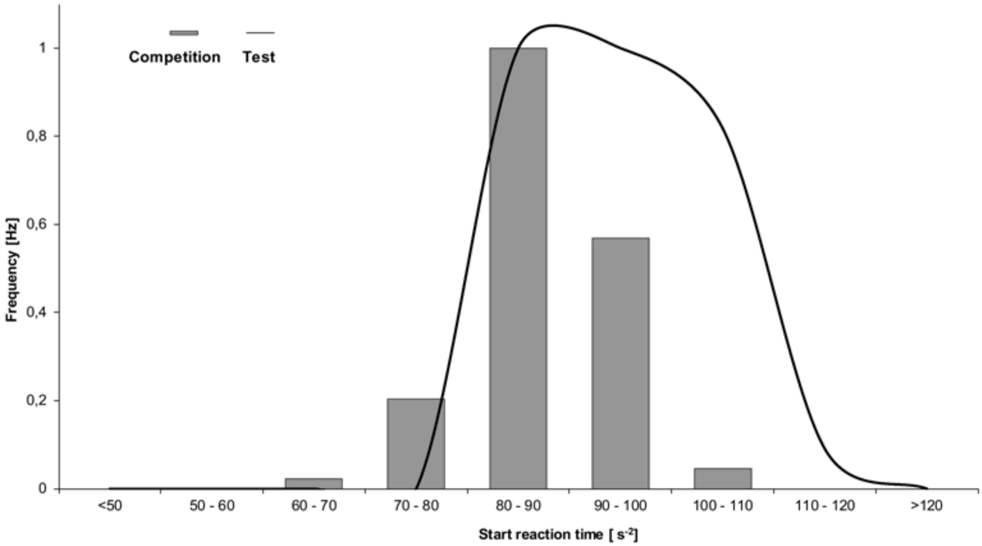

FIGURE 1. Histogram of startup reaction in the group of 13–14 year old females

TABLE 2. Value of the statistics for the distance of 100 m IM and its components of 25 m sections with the considered scores

Variables	N	$\bar{x}$	Min	Max	F	SD	V%
Result 100 medley	40	81.76	68.80	105.43	35.20	5.93	7.25
Points 100 medley	40	89.42	67.00	102.00	73.84	8.59	9.60
Result (s) butterfly	40	17.16	14.23	22.18	2.23	1.49	8.70
Points butterfly	40	7.40	5.00	9.00	1.32	1.15	15.54
Result (s) backstroke	40	21.02	17.61	25.54	2.79	1.67	7.95
Points backstroke	40	9.97	7.00	12.00	1.97	1.40	14.08
Result (s) breaststroke	40	24.18	18.96	32.26	4.94	2.22	9.19
Points breaststroke	40	10.62	7.00	13.00	2.95	1.71	16.18
Result (s) freestyle	40	19.27	14.43	25.45	2.70	1.64	8.53
Points butterfly	40	10.20	6.00	19.00	5.03	2.24	22.00

TABLE 3. Spearman's rank order correlation for the results obtained at the test distance of 100 m IM and its components in relation to the point indicators of the evaluation of swimming techniques

Correlated parameters	N	R	t(N-2)	p-level
Time (s) 100 and points 100 medley	40	–0.47	–3.34	**0.001**
Time (s) and points butterfly	40	–0.36	–2.43	**0.019**
Time (s) 25 and points backstroke	40	–0.52	–3.78	**0.0005**
Time (s) and points breastroke	40	–0.17	–1.09	0.281
Time (s) and points freestyle	40	–0.51	–3.65	**0.0007**

In bold – statistically significant differences ($p < 0.05$) between variables tested.

As is apparent from Tab. 3, concerning the correlation of Spearman's rank order at the test distance of 100 m IM, and its components in relation to the point indicators of the evaluation of swimming techniques, it is noted that there was a statistically significant dependence ($p < 0.05$) between these variables, both at the whole distance of 100 m, as well as in the sections covered in butterfly, backstroke and freestyle – with the exception of breaststroke.

Based on the results shown in Fig. 2, one can determine the direction and strength of the correlation relationship between the result over in the 100 m IM, and the point indicator of movement techniques. These dependencies have proved to be negative and it seems like a fairly strong force. Negative relationship in this case mean that a better result of covering the distance (time 100 m) in IM was accompanied by increased rates of point (points 100 medley) in the observed female swimmers.

Below, in Fig. 3, the diagrams are shown of the dispersion of indicators of point assessment of specific techniques, in relation to the results obtained at different distances of 25 m.

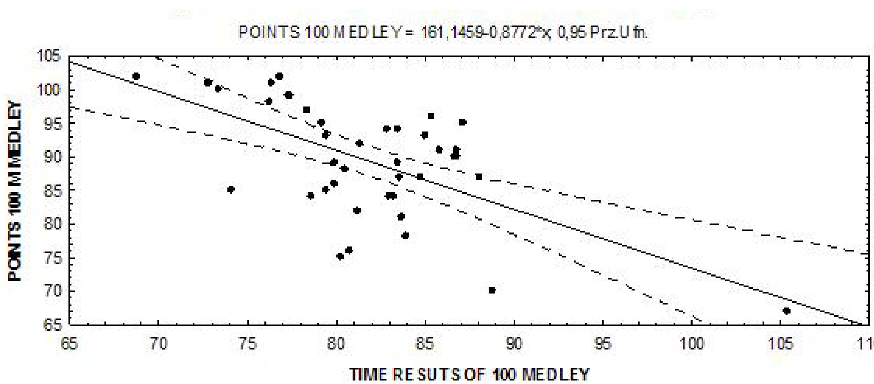

FIGURE 2. The diagram of the dispersion of point indicators of the evaluation of technique against results obtained in sections of 100 m IM

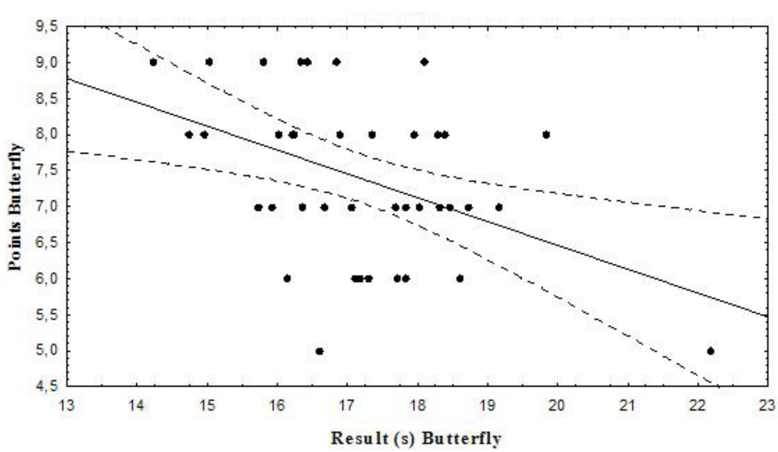

FIGURE 3. Diagram of the dispersion of point indicators in the evaluation of technique against results obtained at different sections of the 100 m individual medley – 25 m butterfly

Shown in Fig. 3–5 and 6, are graphs of dispersion of point indicators of assessment of swimming techniques against the results obtained at different sections of the 100 m IM in backstroke, butterfly and freestyle. The trend visible in the swimmers is that they achieve better results with the growth in point rates, with the exception of breaststroke style.

As is apparent from the data presented in Tab. 4, for Spearman's rank order correlation in the area of considered parameters in section I, 100 m distance – 25 m butterfly, it is noted that there was a statistically significant dependence ($p < 0.05$) between: stroke rate (SR) and the stroke length (SL), swimming speed (V), and swimming efficiency (SE INDEX), indicators of localized assessment of swimming techniques (points) and swimming speed (V).

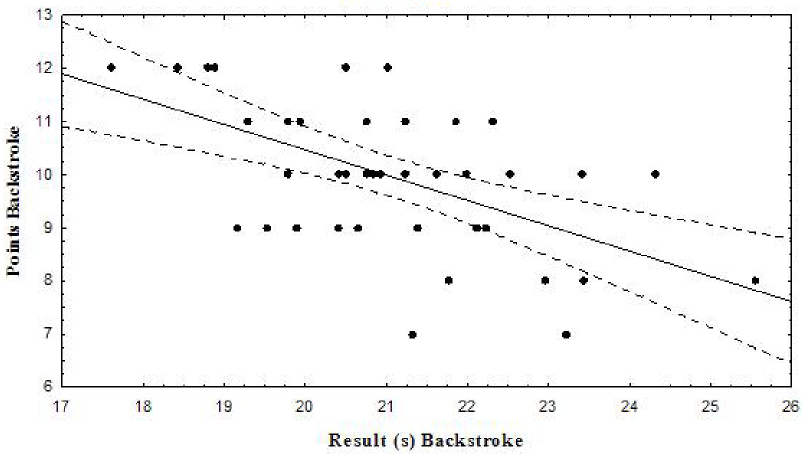

FIGURE 4. Diagram of the dispersion of point indicators in the evaluation of technique against results obtained at different sections of the 100 m individual medley – 25 m backstroke

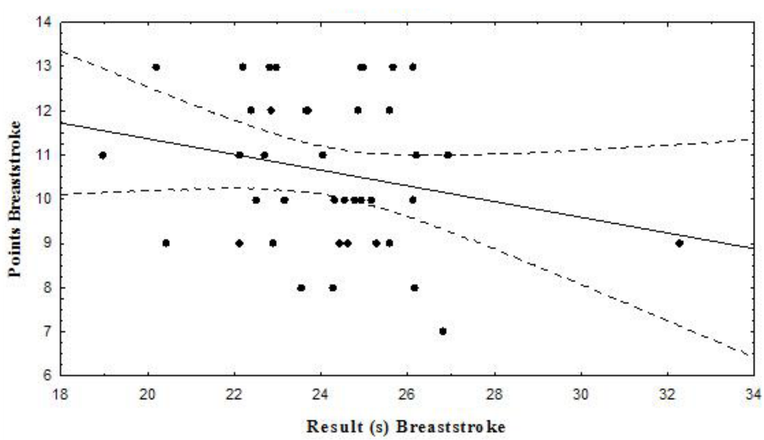

FIGURE 5. Diagram of the dispersion of point indicators in the evaluation of technique against results obtained at different sections of the 100 m individual medley – 25 m breaststroke

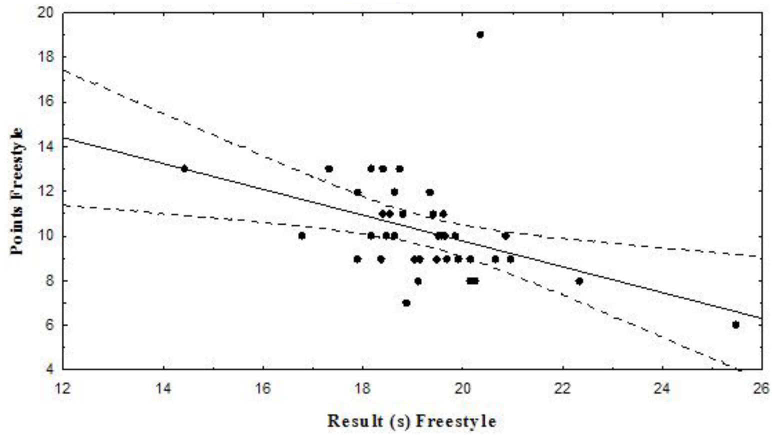

FIGURE 6. Diagram of the dispersion of point indicators in the evaluation of technique against results obtained at different sections of the 100 m individual medley – 25 m freestyle

TABLE 4. Spearman's correlation of rank order between the examined parameters over a distance of 25 m in the butterfly

Test parameters in butterfly	V (m/s)	SR (1/min)	SL (m/c)	SE INDEX	POINTS
V (m/s)	1	0.429	0.182	0.585*	0.675*
SR (1/min)		1	–0.773*	–0.370	0.264
SL (m/c)			1	0.846*	0.175
INDEX [-]				1	0.501
POINTS					1

* significant correlation coefficients (p > 0.05)

Considering the dependences of Spearman's rank order correlation between the examined kinematic parameters in the backstroke (Tab. 5) what was found was a statistically significant relationship at the level (p > 0.05) between: the average swimming speed (V), swimming stroke length (SL) and swimming efficiency index (SE INDEX), stroke rate (SR) and the stroke length (SL), and point index (point G) for swimming techniques at the distance of 25 m in the backstroke.

TABLE 5. Spearman's rank order correlation between the examined parameters over a distance of 25 m in the backstroke style

Test parameters in backstroke	V (m/s)	SR (1/min)	SL (m/c)	SE INDEX	POINTS
V (m/s)	1	0.0521	0.468	0.786*	0.420
SR (1/min)		1	–0.791*	–0.414	–0.050
SL (m/c)			1	0.85*	0.404
INDEX [-]				1	0.556*
POINTS					1

* significant correlation coefficients (p > 0.05)

TABLE 6. Spearman's rank order correlation between the examined parameters over a distance of 25 m in the breaststroke

Test parameters in breaststroke	V (m/s)	SR (1/min)	SL (m/c)	SE INDEX	POINTS
V (m/s)	1	0.625*	0.153	0.514*	0.011
SR (1/min)		1	–0.568*	–0.234	–0.192
SL (m/c)			1	0.914*	0.135
INDEX [-]				1	0.176
POINTS					1

* significant correlation coefficients (p > 0.05)

TABLE 7. Spearman's rank order correlation between the examined parameters over a distance of 25 m in the freestyle

Test parameters in Freestyle	V (m/s)	SR (1/min)	SL (m/c)	INDEX	POINTS
V (m/s)	1	0.087	0.296	0.550*	0.459
SR (1/min)		1	–0.862*	–0.679*	–0.213
SL (m/c)			1	0.939*	0.416
SE INDEX [-]				1	0.480
POINTS					1

* significant correlation coefficients (p > 0.05)

An examination of the relationships between the kinematic parameters in breaststroke style (Tab. 6) indicated that there was a Spearman rank correlation ($p > 0.05$) between: average swimming speed (V) and stroke rate (SR), stroke lenght (SL) and stroke rate (SR), rate of the effectiveness of swimming techniques (SE INDEX). Relations were seen between both an average speed of swimming (V) and the stroke length.

It was not noted in breaststroke that, there was no correlation between the parameters taken into account, and the point indicator of the evaluation of the technique.

At the last stretch of the 100 m IM – 25 m freestyle (Tab. 7), it is noted that statistically significant Spearman's rank correlation ($p > 0.05$) are marked between: stroke length (SL) and stroke rate (SR), and the average swimming speed (V), stroke length (SL) and rate of the effectiveness of swimming techniques (SE INDEX).

In the freestyle there was no significant correlation between the parameters taken into account and the point indicator of the technique evaluation.

DISCUSSION

Based on detailed analysis of both parameters, the effectiveness of swimming techniques and point indicators of swimming techniques in 100 meter individual medley 13–14-year old female swimmers, it can be stated that: the better result in covering both the whole 100 m distance, and the individual 3 sections in butterfly, backstroke and freestyle, were accompanied by a rise in the observed point indicators in the swimmers. This indicates that the outcome affects the quality of swimming techniques for structure and motion trajectory.

Among theorists and practitioners, there is an awareness that the greatest, and not yet fully exploited reserves, lie primarily in how to train young swimmers. This applies in particular to optimize the training activities, monitoring their intensity and the adaptation of physical stimuli applied not only to the current level of physical fitness of the athlete, but and also to the developmental stage of the organism. Only in this way may led training improve stress adaptation mechanisms, give rise to a higher level of physical performance and also create better conditions for modifying swimming technique[12]. The development of technology in the monitoring of swimming technique, operating on different technological configurations (whith both the above-water and the underwater cameras) has become a precise tool for use in a multi-aspect structural analyses of the swimmer's movement. According to Rein Haljand, a professor of biomechanics at the University of Tallinn (Estonia) – swimming technique is a set of consecutive sensory and motor sequences determined spatially and temporally. You can extract and analyze "frame by frame" every moment of movement, sequence, to assess the effectiveness of a swimming technique. Only the coach equipped with such knowledge can choose which exercises, or what language or visualization, should be used in order to improve or adjust the swimming technique[13].

Improvement in swimming performance has been explained in terms of better control of stroke rate and stroke length, in particular with regard to race paces[14], skill due to age[15], and gender[16]. Thanks to modern apparati used in the studies by

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12 Costill D.L., Thomas R., Robergs R.A., Pascoe D., Lambert C., Barr S., Fink W.J., Adaptations to swimming training: influence of training volume, *Medicine and Science in Sport and Exercise*, 1991, no. 23, pp. 371–377; Costill D.L., Maglischo E.W., Richardson A.B., Handbook of sports medicine and science: swimming, Blackwell Science, Oxford, 1992; Mujika I., Busso T., Lacoste L., Barale F., Geyssant A., Chatard J.C., Modeled responses to training and taper in competitive swimmers, *Medicine and Science in Sports and Exercise*, 1996, vol. 28, no. 2, pp. 251–258; Pelayo P., Sidney M., Kherif T., Chollet D., Tourny C., Stroking characteristics in freestyle swimming and relationships with anthropometric characteristics, *Journal of Applied Biomechanics*, 1996, no. 12, pp. 197–206; Pelayo P., Mujika I., Sidney M., Chatard J.C., Blood lactate recovery measurements, training, and performance during a 23-week period of competitive swimming, *European Journal of Applied Physiology and Occupational Physiology*, 1996, no. 74, pp. 107–113; Pelayo P., Dekerle J., Sidney M., Specific indirect measurement of aerobic endurance in swimming and stroking parameters, [in:] Zatoń K., Rejman M. (eds.), Science in Swimming I, AWF, Wrocław, 2007, pp. 69–75; Maglischo, op. cit.; Colwin C.M., Breakthrough swimming, Human Kinetics, Champaign, 2003.

13 Haljand R., Swimming Technique Analyses, Swimming/Notation Canada Prepared by the National Swimming Sport Science Centre – Calgary Practical Coaching Handbook of the Biomechanics of Swimming, 2006.

14 Craig A.B., Pendergast D.R., Relationships of stroke rate, distance per stroke, and velocity in competitive swimming, *Medicine and Science in Sports*, 1979, no. 11, pp. 278–283.

15 Arellano R., Sanchez-Molina J., Navarro F., De Aymerich J., Analysis of 100-m backstroke, breaststroke, butterfly and freestyle swimmers at the 2001 European youth Olympic days, [in:] Chatard J.C. (ed.), Biomechanics and Medicine in Swimming IX, Université de Saint-Etienne, Saint-Etienne, 2003, pp. 255–260.

16 Kolmogorov S.V., Rumyantseva O.A., Gordon B.J., Cappaert J.M., Hydrodynamic characteristics of competitive swimmers of different genders and performance levels, *Journal of Applied Biomechanics*, 1997, no. 13, pp. 88–97.

the Laboratory of Swimming Techniques (in the form of multi-camera registration system of swimming techniques) an in-depth analysis of the structure (and trajectories), and movement techniques of measuring kinematic parameters (for the 100 m individual medley) was carried out. This allowed the retreavl of relevant information relating to the control of the technical level of training of swimmers – proving the system to be an effective tool for assessing the effects of the training process.

One might also assume that further research would be a reasonable extension of the research methods applied, especially measurements of the energy efficiency of swimming conditions, as well as a change in swimming efficiency. For in every race in which swimmers adequate fit the parameters of swimming techniques, the energy cost of effort can be reduced. To this end, this study points to such authors as Pelayo et al.[17] and Dekerle et al.[18] Because changes in swimming endurance are the most important factors in the effectiveness of the training process control[19].

CONCLUSIONS

The following generalization can be reached based on the results of this detailed research:

1. There was no statistically significant correlation between the reaction time of the female swimmers tested, and the result obtained by them over the distance of the 100 m in the individual medley.
2. In all analyzed techniques – elements of the 100 m individual medley – more significant correlations were recorded between kinematic parameters, especially between the swimming performance indicator (SE index) and stroke length (SL) and stroke rate (SR) and swimming speed (V). So one can be led to belive that skillful and conscious control of the swimmers' kinematic parameters (swimming speed, stroke length, stroke rate) may become one of the key aspects affecting the efficiency of swimming techniques and, consequently, the competitive outcome.
3. Point indicators of the evaluation of swimming techniques (points) showed a statistically significant relationship between kinematic parameters in only two cases: the butterfly (swimming speed) and backstroke (indicator of the effectiveness of swimming). It can therefore be assumed that, the level of accuracy of movement techniques in the breaststroke and freestyle (in the 13–14-year old female swimmers exemined) did not contribute visibly to the results obtained in the kinematic parameters.

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17 Pelayo, Dekele, Sidney, op. cit.

18 Dekerle J., Sidney M., Hespel J.M., Pelayo P., Validity and reliability of critical speed, critical stroke rate, and anaerobic capacity in relation to front crawl swimming performances, *International Journal of Sports Medicine*, 2002, no. 23, pp. 93–98; Dekerle J., Pelayo P., Clipet B., Depretz S., Lefevre T., Sidney M., Critical swimming speed does not represent the speed at maximal lactate steady state, *International Journal of Sports Medicine*, 2005, no. 26, pp. 524–530.

19 Zatoń K., Albiński P., Swim stress tests used to assess the capacity of special, [in:] Zatoń M., Jastrzębska A. (eds.), Physiological tests in the assessment of physical fitness [in Polish], PWN, Warszawa, 2010, pp. 105–109.

≈ SCIENCE IN SWIMMING III, 2011, 94–102

The influence of training loads applied in taper period on competitive performance of breaststroke swimming

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INTRODUCTION

Competitive swimming training is a complex process and it should not be presupposed that it has been studied profoundly enough. Even though swimming is now in its heyday in Poland, and Polish swimmers win medals in the most important international competitions, there is still lack of research concerning the application of training loads and analysis of elite swimmers' results. The main aim of training loads applied in all stages of swimming training is to improve the swimmers' performance and to achieve best results during the major competition of each training season[1].

Planning top class swimmers' training requires specifying the length of different stages within the overall program, namely its macrocycles, periods, sub periods and phases, microcycles and workouts. It is a complex process of selecting and specifying optimal proportion of all the means and methods to be used[2].

In the mid-80s a three-cycle structure was established for a one-year macrocycle, supplemented with a 36–42-day taper period[3]. The goal of the taper in competitive swimming is to allow adequate time for recovery from the fatigue associated with the training regimen[4]. The taper scheme that has been used by Polish coaches of elite athletes, since the end of the 1990s includes 6–9 microcycles, which are grouped into 3 distinct phases, i.e.: accumulation, intensification and transformation. Keeping the balance between intensity and amount of exercise during each of these phases is of major importance. A taper consisting of 6 microcycles is generally applied prior to competitions taking place on a 25-meter swimming pool in the winter season.

The first phase, colled accumulation, lasts 19–21 days. The aim of this stage is to maintain the level of basic motor abilities. It comprises a large amount of exer-

1 Klimek-Włodarczak H., The structure and influence of training loads on swimming results over a two year period of training. Doctorial dissertation [in Polish], AWFiS, Gdańsk, 2003.

2 Płatonow W.N., Competitive training in swimming [in Polish], RCMSKFiS, Warszawa, 1997; Ważny Z., The structure of training loads and the method of their recording and analysis [in Polish], *Zeszyty Naukowe AWF we Wrocławiu*, 1982, vol. 27, pp. 71–99.

3 Płatonow, op. cit.

4 Weber M.D., Bullion K.A., Hughes L., Schanz K., Using cardiopulmonary functions to determine the effectiveness of a taper, *Journal of Swimming Research*, 2004, no. 16, pp. 25–30.

cises of low intensity, which in the long run is to increase the level of general fitness and provide the basis for later work on factors, directly determining the performance results. The first microcycle of the accumulation phase is characterized by gradual increase in the amount of exercise with low intensity loads. The two subsequent microcycles are of a 'shock' nature. While maintaining training volume at a high level, the intensity of loads in and out of water is gradually increased. However, the accumulation stage is still dominated by exercise of low intensity.

Next phase of tapering is intensification, which lasts for 11–14 days. The main aim of the training work at this stage is to create the conditions for the development of swimmer's fitness, with the use of various special means of higher intensity. Initially, the amount of training is kept approximately at the same level as during the accumulation stage and then gradually decreased with a simultaneous increase in intensity of loads.

The final phase of taper is transformation lasts for 7–10 days. During this stage both the volume and intensity of the training are considerably decreased. Special exercises are applied and a swimmer's individual adaptive capabilities, and the pace of restitution processes taking place between subsequent training sessions, are taken into account. Much attention is paid to such technical elements as starting, turning and finishing.

A longer taper alternative is used when the swimmers undergo preparation for 50-meter pool races in summer season. In case of swimmer's illness, or any other unpredictable adversities, it may be necessary to make up for missed training sessions. In such cases a longer, 10–12-day taper, is used, by increasing the number of microcycles in the basic mezocycle. Accumulation lasts for 5–6 weeks.

The 12-week taper scheme presented above was used in the case of Otylia Jędrzejczak, currently the best Polish swimmer, in the summer season of 2001. After a longer break in training, due to her secondary school final examinations and change of sports club, it was necessary to make up for the missed sessions and lengthening the accumulation phase and the whole taper. This resulted in a silver medal in the 100-meter butterfly, which Jędrzejczak took in the 2001 World Championships, in Fukuoka. Another example is the 11-week taper scheme of the Polish crawl stroke swimmer, Paulina Barzycka, who placed fourth in 2004 Summer Olympics in Athens, in the 200-meter freestyle.

In this training plan the first 4 weeks are devoted to general endurance and strength training. The overall mileage in water is the highest in the whole taper, and training out of water takes place 4 times a week. Three subsequent weeks are devoted to special endurance and maximum strength training. The intensity of training in water is significantly increased and the dominant part of training is at VO_{2max} level. The next 2 weeks are devoted to intensification, speed training and pace, starting and turning technique. The mileage in water is decreased, similarly to the number of repetitions and series. On the other hand, the intensity of swimming exercises is increased, mainly with the use of the interval method. This method is used in distances at which the swimmer's participation in the main competition is planned.

Final two weeks prior to competition belong to the transformation phase. The amount of exercise in water is decreased significantly and is oriented to speed training. The swimmer's strength is sustained by performing isometric exercises and workout with the use of stretch cords[5]. This taper scheme ends with a microcycle in which technical aerobic training is interchangeably applied with exposure to short speed stimuli (5–15 meters).

Regardless of which taper scheme was chosen, in the 1–4 weeks before the major competition, all elite athletes having gone through intensive training, focus on physical and mental regeneration and aim at creating conditions for special effort adaptation, through changing the conditions and content of training[6]. According to Weber et al.[7] oxygen consumption at anaerobic threshold and other cardiopulmonary function values, are reliable overall predictors for efficacy of the taper. Current control of these data support the use of a mid-season taper as an opportunity to determine the athlete's individual recovery profile for application to the end-season taper.

Typically the notion of "tapering" refers to the last stage of training, which is a stage of resting, and lasts for 2–5 weeks. In that period, the pool training volume should be reduced by 30 to 75% progressively[8]. Properly introduced tapering stage allows the swimmers to improve their results by 3–4%[9]. Mujika et al.[10] suggest that taking part in competition of lower importance, just before the taper, may positively influence an athlete's performance in the main event. As an example they present the results of 99 swimmers who started in Australian Grand Prix competitions three weeks before Olympic Games in Sydney. There were 91 athletes from the analyzed group improved their performance by 1.14% – 6.02%. Most popular practice applied in swimming training is to plan one main participation in a competition in a given season, which involves introducing one taper. According to Maglischo[11] most coaches and athletes use tapering twice or more times in one season.

Over the recent years, the schedule of swimming competitions has significantly changed. The European Swimming League (LEN) and the World Swimming Federation (FINA) have introduced an additional number of competitions of European and world rank, which has complicated periodization of a training program, and brought the need to verify the main competitions included in the swimmers' schedules. At the same time, the frequency of tapering within a one-year macrocycle has increased.

However, most experts including Bompa[12], suggest that more taper periods (3–5) in one competitive season results in the loss of precious time needed for training. In a one year-long training schedule, tapering lasting for 2–4 weeks and applied several times over a season, must be added to several breaks required for

5 Drynkowski Ł., Hard work attracts the talented [in Polish], *Pływanie*, 2006, no. 3, pp. 26–28.
6 Płatonow, op. cit.
7 Weber, Bullion, Hughes, op. cit.
8 Kubukeli Z.N., Noakes T.D., Dennis S.C., Training techniques to improve endurance exercise performances, *Sports Medicine*, 2002, vol. 32, no. 8, pp. 489–509.
9 Costill D.L., Maglischo E.W., Richardson A.B., Swimming, Blackwell Science, Oxford, 1992; Maglischo E.W., Swimming even faster, Mayfield Publishing, Mountain View, 1993.
10 Mujika I., Padilla S., Pyne D., Swimming performance changes during the final of three weeks of training leading to the Sydney 2000 Olympic Games, *International Journal of Sports Medicine*, 2002, vol. 23, no. 8, pp. 582–587.
11 Maglischo, op. cit.
12 Bompa T.O., Theory and methodology of training, Kendall Hunt, Dubuque, 1983.

the athlete's physical and mental regeneration. As a consequence, the total time of planned workout decreases by approximately 50%[13]. Thus, efficient planning of the training loads for particular stages are so crucial, especially in taper period. A poorly planned or improperly conducted taper period may waste the swimmer's effort of the preparation stage, while a well-conducted taper phase may improve performance, even by several percent[14].

During the taper period the training loads are usually applied individually to each swimmer. The complexity of human physiology makes the balance between work and rest sensitive to a number of different factors. Age, gender, or even the duration and number of previous training sessions, and individual regeneration abilities after an exhausting training, have an impact on the results achieved in swimming[15]. A solid training basis is essential for any swimmer to attain top performance. Those who train exactly according to their one-year guidelines, are able to maintain the high level of specific fitness longer, and can achieve peak performances more frequently than those who trained only through some part of the year. Currently, top-class swimmers take part in two or even three major competitions in one year, after they have gone through a special training stage – tapering.

The aim of the study was to specify the relations between training loads used in taper period and the results achieved by an elite 100 and 200-meter breaststroke female swimmer.

The following questions were posed within the study:

- Were there any correlations between the results achieved in 100 and 200-meter breaststroke and the volume of training in taper period?
- What were the correlations between the results achieved in 100 and 200-meter breaststroke and the training loads applied in particular stages of the taper period?
- The loads of which the taper phase showed the highest correlations with the results achieved in 100 and 200-meter distances?

METHODS

The study included a female athlete from Polish Olympic team who for many years, was among the world leaders in the breaststroke. Training loads of seven taper periods for the World and European Championships were analyzed. The training took place on a 25-meter long swimming pool. All taper periods investigated in the study were numbered from 1 to 7 according to the order in which they were applied. Tab. 1 shows a list of all the main competitions with their categories, location, time and performance results achieved by the swimmer in the 100 and 200-meter breaststroke. The correlations between variables were estimated by Pearson's product moment correlation (r).

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13 Maglischo, op. cit.

14 Rakowski M., Changes in the training load of young swimmers in the period of direct preparation for competition (case study) [in Polish], *Sport Wyczynowy*, 2006, no. 7–8, pp. 30–34.

15 Maglischo, op. cit.

TABLE 1. Results achieved in 100 and 200-meter breaststroke during international competitions

Kind of sport event	Location	Date	Distance of breaststroke race			
			100 m		200 m	
			result	place	result	place
1. World Champs	Rio de Janeiro	1–3.12.1995	1:08,96	V	2:26:65	III
2. European Champs	Rostock	13–15.12.1996	1:08,33	III	2:26:11	I
3. World Champs	Göteborg	17–20.04.1997	1:08,33	II	2:25:62	III
4. European Champs	Sheffield	10–13.12.1998	1:07,71	I	2:25:18	I
5. World Champs	Hong Kong	1–4.04.1999	1:07,89	IV	2:25:31	IV
6. World Champs	Athens	16–19.03.2000	1:07,69	II	2:24:24	II
7. European Champs	Valencia	14–17.12.2000	1:06,95	I	2:24:17	II

RESULTS

The longest taper phase (4) lasted 38 days and was to prepare the swimmer for the European Championships in Sheffield in 1998 (Tab. 2). The other six took 36–37 days each. The shortest taper period (6) lasted only 29 days, which was caused both by a large number of competitions the swimmer participated in during accumulation phase, and her illness in the third week of tapering. The greatest number of workouts was accomplished by her in taper period (4), in which she swam as many as 404.8 km. Taper period (6) had the smallest number of workouts. The swimmer took part in only 51 training sessions and swam only 217.7 km. In each of the other taper periods, training loads were applied over 61–64 training sessions, during which the swimmer covered from 253.6 km (taper period 3) to 328.8 km (taper period 5). With regard to the mileage, taper period (7) differed from the other ones in that the number of kilometers done in each training session, was relatively small (221.9 km in total).

TABLE 2. Correlations between the amount of training in particular taper periods and the results achieved in 100 and 200-meter breaststroke

Number of taper		Number of training days	Number of training sessions	Mileage (km)
1.		34	63	319.7
2.		37	61	273.4
3.		36	62	253.6
4.		38	69	404.8
5.		36	64	328.8
6.		29	52	217.7
7.		37	61	221.9
r	100 m	–0.099	0.128	0.262
	200 m	0.258	0.413	0.423

The stage of accumulation lasted approximately 17–19 days. Only in two cases, taper period (1) and (7), it was shorter and took only 15 days. The number of accomplished training sessions varied significantly from 16 (taper period 6) to 34 (taper period 4). The greatest distance was covered by the swimmer in taper period (4) – 227.9 km. Due to the fact that the accumulation stage was carried out with the use of starting method, taper period (6) had the smallest mileage – only 30.4 km. Intensification stage took 12–14 days, during which the swimmer accomplished 21–24 training sessions. The number of kilometers covered in the intensification phase varied from 116.4 km (taper period 3) to 155.2 km (taper period 6). During taper period (7) – 80.9 km were covered. Transformation in most cases lasted 6–7 days, in which the swimmer took part in 10–12 training sessions. The shortest transformation lasted only 5 days (taper period 2 and taper period 3), during which the swimmer took part in 8 training sessions and covered 29.0–36.4 km (Tab. 3).

TABLE 3. Completion of training in particular stages of taper

Number of taper		Accumulation			Intensification			Transformation		
		no. of days	no. of sessions	mileage (km)	no. of days	no. of sessions	mileage (km)	no. of days	no. of sessions	mileage (km)
1.		15	27	132.9	12	23	134.0	6	11	52.8
2.		18	30	151.1	14	24	134.0	5	8	29.0
3.		19	31	100.8	12	24	116.4	5	8	36.4
4.		19	34	227.9	13	23	126.2	6	12	50.7
5.		18	29	153.3	12	24	139.6	6	11	35.9
6.		17	16	30.4	12	23	155.2	7	12	32.0
7.		15	25	106.5	12	21	80.9	7	10	34.4
r	100 m	0.080	0.254	0.106	0.143	0.654	0.492	–0.648	–0.250	0.368
	200 m	0.078	0.527	0.401	0.330	0.577	0.267	–0.743*	–0.355	0.413

* $p < 0.05$

TABLE 4. Time structure of training in various intensity levels of particular taper periods (accumulation stage)

Accumulation		Intensity levels 1 (hh:mm:ss)	2 (hh:mm:ss)	3 (hh:mm:ss)	4 (hh:mm:ss)	5 (hh:mm:ss)	Sum
Taper 1		02:29:40	20:54:17	07:23:22	04:18:14	00:24:42	35:30:15
Taper 2		03:27:51	07:13:24	13:37:57	02:59:10	02:31:45	29:50:07
Taper 3		04:27:35	06:18:01	10:50:10	01:51:23	00:52:12	24:19:21
Taper 4		18:06:35	29:12:58	07:19:04	02:59:50	00:15:31	57:53:58
Taper 5		11:21:30	18:33:19	04:20:53	01:48:54	00:07:44	36:12:20
Taper 6		02:31:36	01:27:24	02:25:33	00:55:55	00:21:34	07:42:02
Taper 7		08:38:40	13:29:04	01:56:18	01:15:46	00:14:11	25:33:59
r	100 m	–0.464	0.037	0.650	0.748*	0.360	
	200 m	–0.258	0.255	0.746*	0.875*	0.449	

* $p < 0.05$

TABLE 5. Time structure of training in various intensity levels of particular taper periods (intensification stage)

Intensification		Intensity levels 1 (hh:mm:ss)	2 (hh:mm:ss)	3 (hh:mm:ss)	4 (hh:mm:ss)	5 (hh:mm:ss)	Sum
Taper 1		08:09:30	13:30:21	04:25:10	03:47:49	00:17:12	30:10:02
Taper 2		03:20:18	04:36:33	06:47:53	02:16:09	01:27:45	18:28:38
Taper 3		02:50:23	05:33:30	19:01:16	01:12:48	00:56:37	29:37:34
Taper 4		08:33:34	15:25:27	03:53:00	01:59:11	00:07:50	29:59:02
Taper 5		10:43:09	17:55:03	03:24:55	01:22:59	00:49:30	34:15:36
Taper 6		02:35:15	18:35:16	08:50:51	04:24:42	00:30:47	34:56:51
Taper 7		06:03:20	11:06:44	00:51:50	01:17:16	00:16:53	19:36:03
r	100 m	–0.009	–0.272	0.375	0.342	0.320	
	200 m	0.172	–0.405	0.170	0.082	0.345	

TABLE 6. Time structure of training in various intensity levels of particular taper periods (transformation stage)

Transformation		Intensity levels 1 (hh:mm:ss)	2 (hh:mm:ss)	3 (hh:mm:ss)	4 (hh:mm:ss)	5 (hh:mm:ss)
Taper 1		03:04:20	01:55:00	00:46:54	01:32:35	00:46:00
Taper 2		00:59:29	01:37:01	03:00:12	01:19:15	00:37:29
Taper 3		02:04:07	03:14:01	01:50:30	03:04:24	00:31:44
Taper 4		05:14:05	04:38:47	00:43:48	00:44:38	00:38:07
Taper 5		02:49:40	05:00:45	00:20:27	00:34:02	00:14:35
Taper 6		01:35:00	01:00:45	01:29:49	01:04:50	00:43:38
Taper 7		01:46:10	04:36:50	00:13:38	00:27:18	00:09:59
r	100 m	0.025	–0.504	0.416	0.590	0.647
	200 m	0.115	–0.269	0.358	0.443	0.454

Training volume applied in the intensification stage did not have any significant correlation with results achieved in the 100 m and 200 m breaststroke races (Tab. 5).

The time structure of the training volume for the particular taper are presented in Tab. 4, 5 and 6. These tables also include the data about intensity levels. The correlation between training volume in accumulation stage, and the performance result achieved in the 100 m breaststroke, showed the greatest significance in the fourth and then, in the third intensity level (Tab. 4). Similar results have been found when analyzing 200 m breaststroke; in this case the correlations were more distinct.

Relatively low liaisons were found between performance results and the transformation stage (Tab. 6). The fifth level of intensity was exceptional, because the value of correlation was the highest there (r = 0.647).

DISCUSSION

The results of the study on training loads in taper periods allowed for making various comparisons of their structure and extensiveness and assessing their impact on the performance results achieved in main swimming competition. The system of tapering in case of top-class swimmers for major competitions has been insufficiently studied and is still not always effectively used. In their publications, experts on the theory of sport and swimming training describe several different variants of taper periods[16].

The 6-week taper period variant presented above is similar to that of the American school of training. The average number of days in the taper periods analyzed was 35–36. Because of a general tendency by German and Russian coaches to use high training volumes, the schedule of loads in particular stages of the analyzed taper periods significantly differs from the parameters, which were achieved by the swimmer in the present study.

An analysis of the results showed that only one taper period (4) resulted in the value described by experts and sport theoreticians. The stage of accumulation turned out to be the longest in taper phase (4): 17–18 days, with 71 h 15 min 18 s load and 227.9 km covered; which in comparison to the values of the basic mezocycle presented, is not even within the lower limit (84 h – 20 days of work, 240–310 km). Loads in the accumulation stages of the rest of the taper periods were lower, however similar to one another. The lowest load was that of accumulation in taper period (6), which could be justified by the fact that the swimmer took part in the great number of competitions in the initial stage of preparations, and went through an illness in its second stage.

In both of the main competitions, namely after taper period (4), in which loads in the accumulation stage were significant, and after temper phase (6), in which she practically did not train at all, the swimmer achieved similar results. It may therefore be assumed, that in the case of a mature and experienced top-class swimmer, who systematically trains according to a one-year schedule, it is not necessary to apply large loads during the accumulation stage. The findings prove that training in this stage has no significant influence on the final results in a competition. This standpoint can be confirmed by other findings. Thomas et al.[17] claim that optimal reduction of training volume during taper period depends on the total amount of training loads applied prior to the taper. Excessive training volume may in mature competitors, result in weariness, boredom and discouragement from undertaking further efforts. It should be pointed out that, proper intensification of the training, and a training course in the intensification stage, have significant influence on the results. The case of the best Polish swimmer during the last few years, Otylia

[16] Costill D.L. Thomas R., Robergs R.A., Pascoe D., Lambert C., Barr S., Fink W.J., Adaptations to swimming training: influence of training volume, *Medicine and Science in Sport and Exercise*, 1991, no. 3, pp. 371–377; Maglischo, op. cit.; Płatonow W.N., Adaptation in sport [in Polish], RCMSKFiS, Warszawa, 1990; Płatonow, Competitive training…; Sozański H., Gajewski A.K., Kielak D., Kosmol A., Basic theory of sports training [in Polish], COS, Warszawa, 1999.

[17] Thomas L., Mujika I., Busso T., A model study of optimal training reduction during pre-event taper in elite swimmers, *Journal of Sport Sciences*, 2008, vol. 26, no. 6, pp. 643–652.

Jędrzejczak, seems to confirm this claim. After the Olympics in Athens in 2004, where she won one gold and two silver medals, she had a 6-month break devoted exclusively to promoting herself and gaining popularity. Despite a significant lack of training sessions, she broke the world record in the very next training year, and won gold in the World Championships. The level of proficiency in swimming which Jędrzejczak achieved is so high that, with good selection of training means, and proper levels of intensity in the whole macrocycle and taper period, she is able to compete with the top swimmers for the world next few years, having only moderate training loads. It may confidently be said that in the case of top class swimmers, the regaining of the previously achieved level of functional mechanisms of the organism, is very quick.

Physiological and psychological response to applied training loads is strictly individual, therefore it is not possible to create a universal model of taper. Theoreticians of sport and coaches constantly search for the optimal balance between training volume and intensity. In the study of Faude et al.[18] two types of 4-week taper were conducted in two groups: one focused on training volume, the other on training intensity. The correlations between these training loads and sport results (100 m and 400 m) were insignificant in both groups. The effects of taper described in the present study seem to be different. Taking into account the highest correlations between results achieved in 100 m and 200 m breaststroke races, and total amount of workout in the taper accumulation phase, we may conclude that these training loads might have influenced the results.

CONCLUSIONS

The taper period loads presented above may be of some use by coaches in their everyday work. While training new swimmers, they may observe the differences and look for regularities in various tapering models. The abovementioned values may constitute a point of reference in work with particular swimmers and allow coaches to verify training loads for each swimmer individually. Consequently, it will contribute to an increase in swimmers performance. Taking into account the fact that there is little research on training loads in taper periods, the model of loads presented above may facilitate work for many swimming coaches, and contribute to the development of this sports discipline. The analysis of taper training and starting loads in swimming, presented in this study, should also facilitate the individualization of training loads for particular elite breaststroke swimmers.

[18] Faude O., Meyer T., Scharhag J., Weins F., Urhausen A., Kindermann W., Volume versus intensity in the training of competitive swimmers, *International Journal of Sports Medicine*, 2008, vol. 29, no. 11, pp. 906–912.

≋ SCIENCE IN SWIMMING III, 2011, 103–112

Analysis of swimming high jumps

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INTRODUCTION

Competitive swimming results are influenced by the start, the turn, the whole distance and the finish speed. It is common to separate those actions in segments. The execution of the start technique, and better start result, helps to overcome those contestants who figure to get advantage in the finish. The authors who were investigating different start positions define no technical benefits in them. It is not so important whether the swimmer's legs are parallel to the front edge of the block, or whether they are in the runner's starting position, or whether or not the sportsman keeps tight at the edge of the starting block – the most important thing is the takeoff jump[1]. An analysis of Lithuanian swimmers' revealed the fact that, even the members of this national team, are not very effective in successful executing the start[2].

Those swimmers, who accomplish the start faster than the other competitors, more often win in the sprint swimming distances than those, who complete the distance faster. Despite the fact that different jumps executed on the tenzoplatform are variant from swimming movements in locomotoric conditions (solid and liquid), the same groups of leg muscles are involved. They have a close functional relation in both swimming and jumping.

The particularity of training process control is the fact that the person, who manages the self-control system, is involved in the process. The reactions of this system determine the consistent pattern of its functioning. This pattern is not very

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1 Arellano R., García F., Gavilán A., Pardillo S., Temporal analysis of the starting technique in freestyle swimming, [in:] Abratnes J.M.C.S. (ed.), Proceedings of the XIV Symposium on Biomechanics in Sports, Technical University of Lisbon, Lisbon, 1996, pp. 289–292; Blanksby B., Nicholson L., Elliott B., Biomechanical analysis of the grab, track and handle swimming starts: An intervention study, *Sport Biomechanics*, 2002, no. 1, pp. 11–24; McLean S.P., Holthe M.J., Vint P.F., Beckett K.D., Hinrichs R.N., Addition of an approach to swimming relay start, *Journal of Applied Biomechanics*, 2000, no. 16, pp. 342–355.

2 Satkunskienė D., Lagūnavičienė N., The characteristics of kinematic parameters in swimming races based on the example of Lithuanian Olympians [in Lithuanian], [in:] Didelio meistriškumo sportininkų rengimo valdymas, 1997, pp. 44–48; Zuozienė I.-J., Skyrienė V., In search of parameters defining the effectiveness of conquering the start phase in swimming [in Russian], [in:] Ermakov S.S. (ed.), Pedagogy, psychology and health problems in physical education, Harkov: HDADM (XXIII), 2009, no. 1, pp. 64–69.

well known. If we want to describe the human movement potential in mathematical terms it is purposeful to use the language of multidimensional space theory and multidimensional statistic analysis. The aspects of modeling for sport are provided in this work.

For research with living organisms, it is necessary to create new models, which have no analogy in other science and technical branches. The example of the human musculoskeletal system, which has more than 200 degrees of freedom, facilitates the demonstration of the peculiarity of living movement systems. Despite the complexity of the system, human beings react very quickly, and under perfectly control, even when influenced by outer factors. Such a problem might have dozens of variables related to muscle activity, because while executing any movement, more than several muscles act simultaneously, but the human body solves this problem within seconds or even milliseconds – much faster than modern counting machines. So far there is no model which could embrace the whole human body, and in spite of the fast development of computer software and hardware, many living organism systems are being designed separately from each other. Only the human musculoskeletal system makes an exception in this case. As opposed to the other bodily systems fulfilling vital function, whose activities are based on different chemical and physiological processes, the musculoskeletal system is the most similar to the operations of common engineering system. The only difference is in the specific power elements which ensure mechanical movement – the muscles. Though it is obvious that the human body is unable to function without any of its systems, it is possible to make an exception in the case of the musculoskeletal system, and design models of it separately, or together with the nervous system.

Geometry. When doing research on the laws of human movement, the geometrical forms and omitted measurements of segments, have practically no influence (unless the movement is being investigated in an environment which is much more viscous than air, or is a movement in high speed air flow) but this counting model is much simpler. Therefore, in some cases, movement modeling and analysis, are which concentrate on parameter models, where the main human body segments are described as absolutely rigid pivot elements, and which have certain inertness and mass qualities, with their movement being described in Newtons, Euler Equations of Motion. If it is necessary to evaluate only the outer body or the form and measurements of its segments, it is possible to use a less simplified model, in which the absolutely rigid pivot elements are the bones (usually – long), and where the repetition of a body segment in such a bone might be “dressed” in weightless integument, adequate in form and measurements, and with the real mass of body segment evenly allocated.

While modeling separately chosen human body segments or several segment systems (usually to solve a non dynamic problem) it is obligatory to pay attention to the geometric form and measurements of these segments and their copula.

When analyzing movement, muscles are mostly being modeled as chords with a very small cross-sectional area, in comparison with their length, but which are not allowed to bend or compress. In solving converse dynamic problems, the “chord” tension power variations are detected, when accomplishing certain movement, and in solving direct dynamic problems, these “chords” are used for the formation of model movement. Muscles are attached to the bones through tendons and ligaments, which in all the cases of movement analysis, are being modeled only as very flexible elements of certain resiliency.

In order to investigate the power created by muscular activity, the models which correspond to their geometric shape, are created and separated into elements. Their shape and alignment are close to the shape and alignment of muscle fiber. In such a way the model of muscle activity is more adequate to reality.

Movement formation. Human being can only move using the musculoskeletal system. This system consists of short and long levers – bones attached by mobile links – joints and moving muscles, operated by nerves. The bones and their links are the passive parts of the moving system, while the muscles and nerves system are the active ones. The main feature of the muscles is its ability of contract and make the other segments of the body to change their internecine position thus moving the body. The purpose of the liniments and connective capsules, which join bone to bone is to strengthen mechanical stability of the links, is to hold the movement of the links and to limit excessively wide movements of the body links. Thus, these structures are passive, for unlike the muscles, they do not create any movements. In certain cases muscles can be considered as passive elements of the movement apparatus. Such cases emerge when so called passive dynamics problem is being solved; when the muscles do not form any movements and just keep certain posture of the skeleton (it is enough to determine axial rigidity and suppression of the muscles). Both during passive and active musculoskeletal dynamic analyses, when the muscular power and resiliency are evaluated; it is also very important to evaluate the alternation of each muscle shape (position, configuration) and the position of the places where the muscles and the bones are joined (when specific individual is being tested all these parameters might be defined using magnetic resonance equipment or the other non-contact methods).

In order to describe muscles as power generating elements, special muscle models are used, which embrace contractile component, which generates muscle power, coherently and linked in parallel to resilient elements. The universal muscle, model including both muscle and tendons also possesses suppression element (Fig. 1).

In many cases during movement analysis, in order to ensure due movement for its formative "model's muscles", an appropriate stimulation signal is indicated, which imitates the central nervous system signals sent to the certain muscles. Another case of movement analysis is muscle control using hypothetical signals – ensure optimal or ultimate power activity of that muscle. The first method is implemented on the base of the laws of muscular activity measurements (electromyographic models) while the second uses the so called optimizing models. The main drawbacks of electromyographic models are the problematic measurement

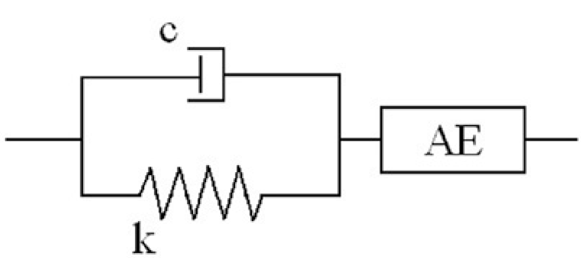


FIGURE 1. Muscle-tendon model
k – resilient element
c – suppression element
AE – active element (contractile, power generating)

of muscle activity and the impact of the measurement process on an object which is being measured. In addition, to the use of models, covering a smaller (or larger) number of muscles than those actually involved in forming a movement, it is difficult to re-control signals. This is quite complex as the high frequency signal transformation in muscle patterns of use a form suitable for low frequency signals.

For the foregoing reasons, human movement analysis is an increasingly popular methods of optimization, the essence of which is that it aims to determine which combination of control signals produces a result which corresponds to the optimum (minimum, maximum) of a selected criteria. Such a (cost) function estimate analysis can be very simple. The objective function can be either directly related to muscle activity (e.g., minimization of muscle work performed) or occur the movement (for example, to maximize a high jump result). For quite well before hand (with inverse dynamic analysis models) static optimization models, deficiencies in the latter, the most common use of dynamic optimization models (along with the direct analysis of dynamic models). Unlike the inverse dynamic analysis (inverse dynamics) to identify the forces and moments for assessing the strength of moving elements and coaster kinematic properties, the direct dynamic analysis (forward dynamic) in the simulated movement of body segments shows hinge joint torques. Defined muscle control signal combinations ensure the optimum choice movement. Dynamic optimization method can be used when it is not possible to determine the specific criteria (e.g. jump height, etc.). In some cases (e.g., a jump analysis) an optimal control model is used for various theoretical parameters, to investigate whether the solutions obtained by using the comparative value of the function (tracking cost function) to evaluate the modeled movement (kinematic, kinetic, EMG) are in compliance with the parameters of the experimental results of the examination.

Border conditions. A border conditions biomechanical modeling systems, as already mentioned, is basically similar to some used in engineering analysis, but also exerts a certain specificity, which results from both the studied object and its surrounding environment. For example, on the whole body, movement in an environment often has a modeling framework within which it moves, to evaluate the body in contact with the movement of the interfering environmental elements, which are relatively easy to identify in model parameters (i.e. the model – global) but which are problematic when it comes to assessing the elements present and in contact. Load modeling biomechanical systems are also often quite specific, for example, usually only modeling the home influence of the weight of the system (body or its segments) movement and the like. Initial model conditions are used to simulate the biomechanics of the human movement system, and they can be seen as the complementary sides of information on system configuration at the certain time.

The aim of this study is the analysis of methods for determining human biomechanical parameters in high jump performance and high jump modelling. To reach this aim, the following objectives were raised:

1. To determine the patterns in human support apparatus during high jump performance by comparing different types of high jump.
2. To create a complex computer model for the evaluation of separate muscles influencing high jump efficiency.

METHODS

The human movement analysis was done in two stages: (1) the experimental research was performed and the side model condition obtained; (2) computer-based human model was created and calculations done. The analysis was performed in the following order:

1. By recording the subjects' high jump with equipment for measurement and analysis of 3D movements, the trajectories of human body control points, patterns of change in joint angles, patterns of movement of body segments – velocities and accelerations were determined.
2 According to the person's anthropometric data (height, weight, body proportions), using software for biomechanical analysis, computerized biomechanical model is created that corresponds to the subject's support locomotion apparatus, including bones, joints and muscles.
3. On the basis of a biomechanical model for the inverse dynamics analysis, patterns of muscle activity were determined, that enable the movement of a model corresponding to the subject's movement, measured in the experiment.

The subjects in the research were 6 male swimmers aged 20–22 who are the members of the swimming team of the Lithuanian Academy of Physical Education.

The Optical Motion Capture 3D analysis system Qualisys ProReflex was applied for high jump analysis. It consists of 4 synchronically acting 400 Hz video cameras, a power measuring platform and Qualisys Track Manager 3D software (this equipment was used for getting basic data needed for jump modeling).

QUALISYS movement measuring and experimental analysis software, with four robust cameras set in particular order around the subject performing high jumps, filmed and compiled the information about the subject's upward movement (benchmark dimensional coordinate variation) (Fig. 2). The information received from a special computer plate was synchronically converted into cor-

FIGURE 2. 3D experimental movement analysis software

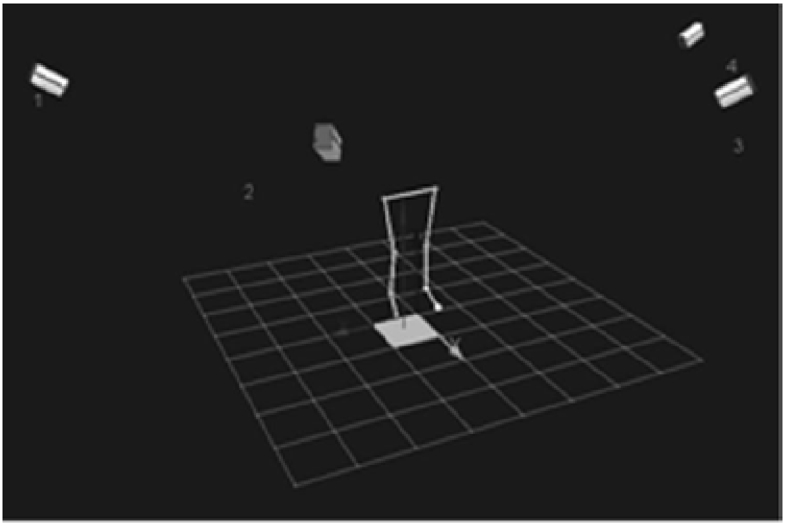


FIGURE 3. Cyberspace where the measurements of movements are run

responding digital signals which are automatically recognized and processed by dimensional movement analysis software, and formed into computer-based moving human model shown in the monitor (Fig. 3).

Special markers were attached to the subjects for the measurements of human body benchmarks. They had to be attached exactly to those places which correspond to the computer-based movement modeling software benchmarks (Fig. 4) because during the filming, the benchmark moving trajectories were latter used for computer modeling.

FIGURE 4. Marker positioning

The data received during the filming was automatically processed (filtered, compressed, interpolated) directly at measuring (Fig. 5). Body point movement, the velocities and accelerations of segments were depicted graphically and saved in database.

During the test, the subjects performed two types of high jumps: (1) maximum high jump; (2) explosive high jump. These tests were intended to evaluate athlete's strength and related physical conditions (dynamic strength, coordination, etc.).

After a light 10 min. warm-up, each subject performed 5 maximum high jumps and 1 explosive high jumps. The starting position for the high jump was standing, knee-bend at 90° angle, vertical body position, hands on the hips. The break between jumps was 30 s. Non-qualitative jumps were rejected.

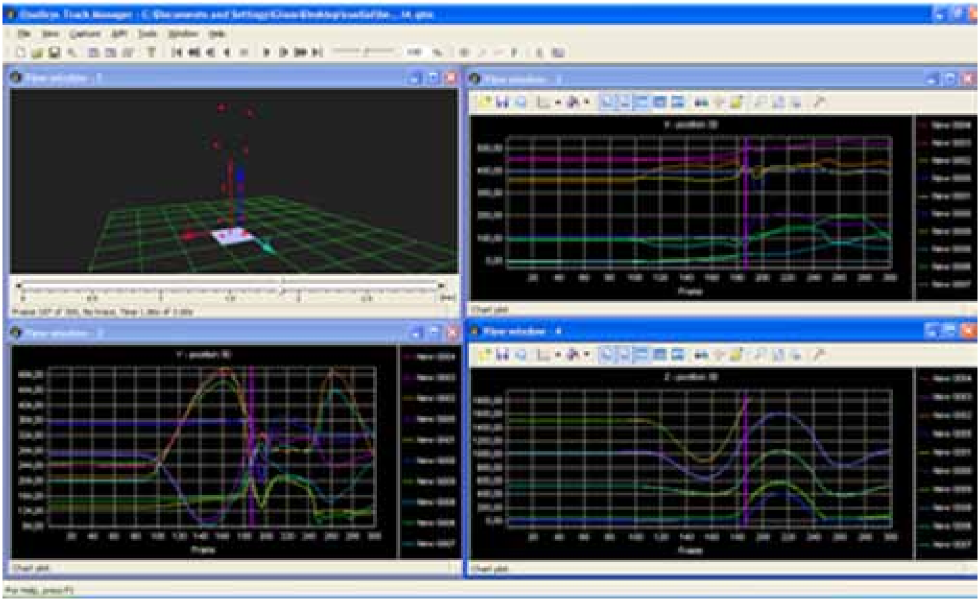


FIGURE 5. Dimensional benchmark positioning and coordinate variations on the system of axes

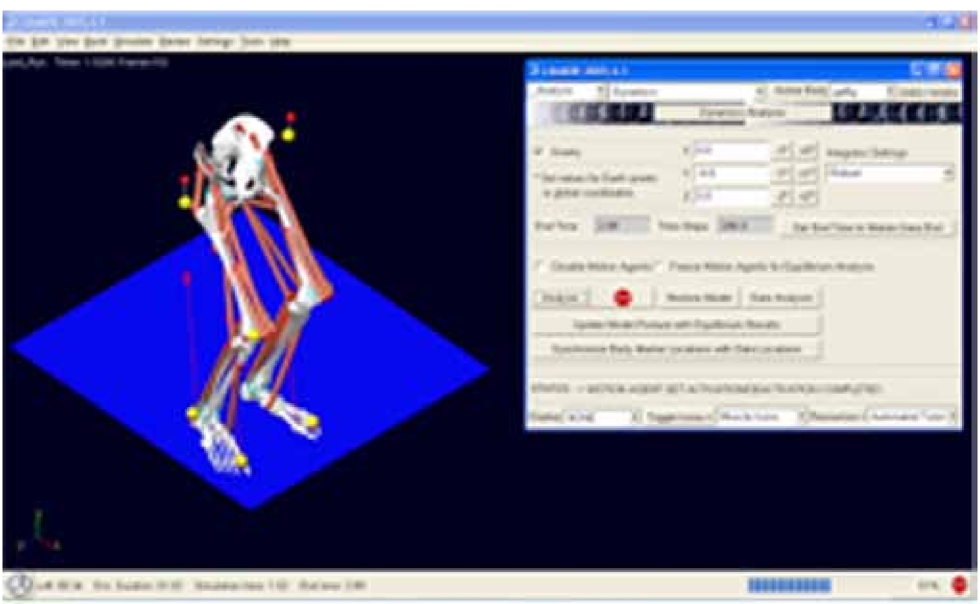


FIGURE 6. Computer-based biomechanical model of lower body part for jump analysis (bones, joints and muscles)

RESULTS

Applying biomechanical analysis software, according to the subject's anthropometric data (Tab. 1), a computer-based biomechanical model was designed corresponding to the subject's lower body, support and movement apparatus (bones, joints, muscles) which are used for movement performance (Fig. 6). In high jump analysis, such model encompasses: the pelvic bone, femur bones, shinbones,

TABLE 1. LifeMOD in terms of computerize

Parameters	Remarks
$--UNITS [UNITS]	Measurements
LENGTH = 'millimeter'	Height, mm
FORCE = 'newton'	Force, N
ANGLE = 'degrees'	Angles, degrees
MASS = 'kg'	Mass, kg
TIME = 'second'	Time, s
$------------ANTHROPOMETRIC_DATA [ANTHROPOMETRIC_DATA]	Antrhropometric data
SUBJECT_NAME = 'gal3a'	Subject name (code)
GENDER = 1.0	Gender (1 – mascul., 2 – fem.)
TOTAL_BODY_HEIGHT = 1900	Height, mm
TOTAL_BODY_MASS = 90.00	Mass, kg
AGE = 276	Age, months
HANDS = 1	
NOHAT = 1	
$---------------------------------MARKER_SET [MARKER_SET]	Marking (1st ap.)
TYPE = 'Davis'	
T4 = 'OFF'	OFF – inactive markers
RSHO = 'OFF'	ON – active markers
RHUW = 'OFF'	
RASIS = 'ON'	
RFEMW = 'OFF'	
RFEMC = 'ON'	
RTIBW = 'OFF'	
RLATM = 'ON'	
LWRI = 'OFF'	
LASIS = 'ON'	
LFEMW = 'OFF'	
LFEMC = 'ON'	
LHEEL = 'OFF'	
L2MET = 'ON'	
SHFT = 'OFF'	
$-------------------------------------MOTION_DATA [MOTION_DATA]	Movement data (2nd ap.)

splint-bones, foot bones, connective hip, knee and ankle muscles and the main lower limbs muscles i.e., muscles that move the thigh, muscles that move the leg and muscles that move the feet and toes.

Those segments which are not used in modeling the jump were deactivated. They include: degree of joint, which does not highly influence the motion, flexibility is fixed (e.g. knee joint can be bent only in the sagittal plane). The rest were modeled as passive, they are given certain angular rigidity and suppression (Tab. 2).

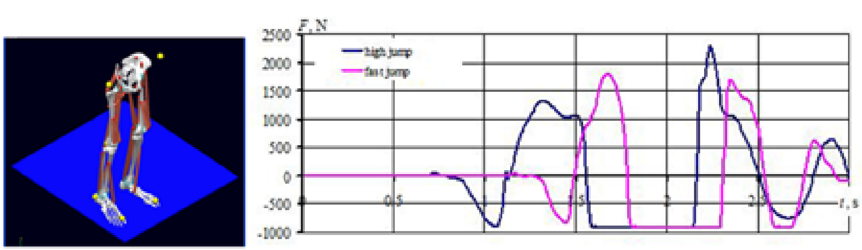
To reflect the dynamics of motions in the model that would correspond to the subject's movements, trajectories of control points were indicated in the model and patterns of muscle activity were calculated, to ensure the motions that were determined during the test.

TABLE 2. Activated joint parameters

Joint	Axes	Angular rigidity N · mm/ degrees	Angular suppresion, N · mm · s/ degrees	Freedom interval, degrees	Angular rigidity On the verge of movement freedom N · mm/degrees
Hip joint	X	100	1000	50–120	10^6
Hip joint	Y	100	1000	30–30	10^6
Hip joint	Z	100	1000	60–60	10^6
Knee joint	X	100	1000	160–10	10^6
Knee joint	Y	Fixed freedom degree			
Knee joint	Z	Fixed freedom degree			
Ankle joint	X	100	1000	50–120	10^6
Ankle joint	Y	Fixed freedom degree			
Ankle joint	Z	Fixed freedom degree			

Fig. 7 displays LifeMOD the dynamic analysis and MC reaction power during maximum and explosive high jumps.

Fig. 8 and Fig. 9 depict the variation of main leg muscle force during tested jumps (left and right leg).



a b

FIGURE 7. Dynamics analysis: a – LifeMOD (movement forming markers), b – MC reaction power

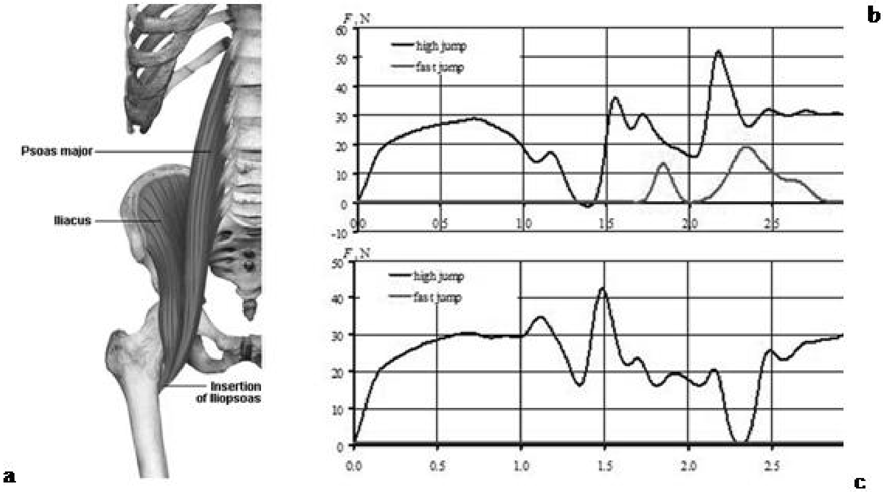


FIGURE 8. Hip Iliacus muscle: a – variation during the jump, b – left leg, c – right leg

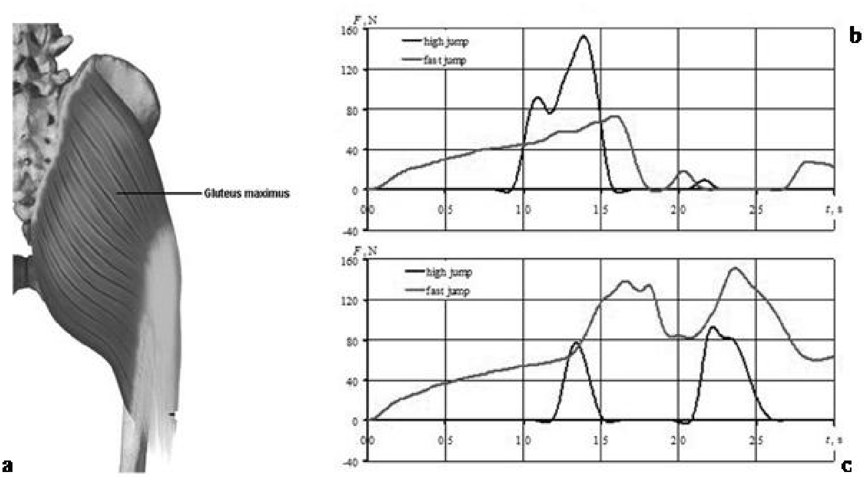


FIGURE 9. Sacral Gluteus Maximus: a – variation during the jump, b – left leg, c – right leg

CONCLUSIONS

It was determined that the activity of the hip muscle and central double shin muscle is up to 50% higher at explosive high jumps, and the activity of side double shin muscle is up to 40% higher at maximum high jumps. By applying 3D mathematical model of human support-locomotion system the effect of lower body muscles on jump height was determined. The forces developed by the muscles of different legs during high jumps differ up to 10%. From the computer analysis of the high jumps of different types, the activities of different muscle were determined in performing maximum high jump and explosive high jump.

≈ SCIENCE IN SWIMMING III, 2011, 113–122

Execution of selected angles in the Front Pike and Surface Arch positions in synchronized swimming

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INTRODUCTION

The knowledge of precise structure of movement is one of determinants of success in sport. To achieve this success individual sequences of movement should be identified and thoroughly analyzed. This is particularly important in complex sports[1], in which training relies on the development of specific coordination skills[2]. One of such sports is synchronized swimming, in which swimmers must possess the necessary skills to recreate compulsory figures and complex technical routines, in compliance with respective sport's regulations. Problems faced by synchronized swimmers include the specific conditions of the water environment and exceptional breath control skills underwater. Kinesthetic differentiation and spatiotemporal orientation are also important determinants of sport success[3].

Kinesthetic differentiation of movement is determined by the accuracy of interoceptive senses (proprioceptors) often in combination with sight and hearing senses (teleceptors). Kinesthetic differentiation relies on the so-called proprioception, i.e. transformation of stimuli from proprioceptors in the muscles and joints into information about the position of joint angles, extremities and trunk in relation to one another (feedback on the status of the body internally). The information from the stimuli also concerns the direction and speed of movement of the extremities and resistance, to ensure proper positioning of the body or the extremities. These aspects are crucial in synchronized swimming and subject to such assessment criteria as precision and economy of movement[4].

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1 Starosta W., Selected issues in teaching and improving movement technique (for example in individual sports) [in Polish], *Antropomotoryka*, 1989, no. 2, pp. 9–44.
2 Raczek J., Mynarski W., Ljach W., Formation and diagnosis of coordinated motor abilities [in Polish], AWF, Katowice, 2002.
3 Szopa J., Mleczko E., Żak S., Basic anthropomotorics [in Polish], PWN, Warszawa–Kraków, 1996; Bajdziński M., Starosta W., The kinesthetic differentiation of movement and its considerations [in Polish], Instytut Sportu, Gorzów Wlkp., AWF, Poznań, 2002.
4 Raczek J., Mynarski W., Ljach W., Theoretical-empirical basis for the formation and diagnosis of coordinated motor ability [in Polish], AWF, Katowice, 1998.

Spatiotemporal orientation is a multidimensional ability, whose most characteristic component is its visual aspect. The assessment of spatiotemporal ability must take into account the precision and speed of evaluation of the body's position in relation to particular reference points[5]. In synchronized swimming it is the ability to assess the position of the swimmer's body and body parts in relation to the pool walls, bottom, water surface and routine partners[6].

The Front Pike and Surface Arch positions in synchronized swimming display certain similarities, in terms of technical requirements and judges' evaluation criteria, as well as anatomic requirements. These two positions occur in almost all compulsory figures or technical elements of free routines[7]. The anatomy of hip joints allows the execution of the Front Pike position according to regulations; however, the technical requirements of the Surface Arch position seem controversial. It is commonly thought that the execution of this position in strict compliance with the official FINA rules is impossible.

The aim of the study was to assess the conformity of the degree of selected articular angles in the Surface Arch and Front Pike positions with the official synchronized swimming regulations. The second aim was to assess the degree to which achieving the standard set by the FINA rules for the Surface Arch is possible.

METHODS

The study sample comprised 26 synchronized swimmers from three sports clubs in Poland. The subjects' age ranged from 14 to 21 years, which corresponded to the respective age categories in competitive synchronized swimming:

- younger juniors under (14 subjects);
- older juniors 16–18 years (7 subjects);
- seniors 19 and above (5 subjects).

All the swimmers took part in the measurements at half-year intervals: 14 in one measurement, 7 in two, and 5 in three. The different number of measurements for each age group was related to the availability of sports facilities as well as swimmers themselves. In total, 43 images of each position, were taken during the study.

The movement technique was recorded with a video camera placed 50 cm below the water surface. The swimmers executed the positions sideways to the camera placed 7 meters away (Fig. 1), as seen by the judges during technical routine competitions.

[5] Juras G., Waśkiewicz Z., Raczek J., Spatial-temporal orientation ability: identification, internal structure and diagnostic methods [in Polish], *Antropomotoryka*, 1998, no. 17, pp. 97–121.

[6] Gray J., Coaching synchronised swimming. Figure transitions, Standard studio, Maidenhead, 1993.

[7] Mountjoy M., The Basics of Synchronized Swimming and its Injuries, *Clinics in Sports Medicine*, 1999, vol. 18, no. 2, pp. 321–336.

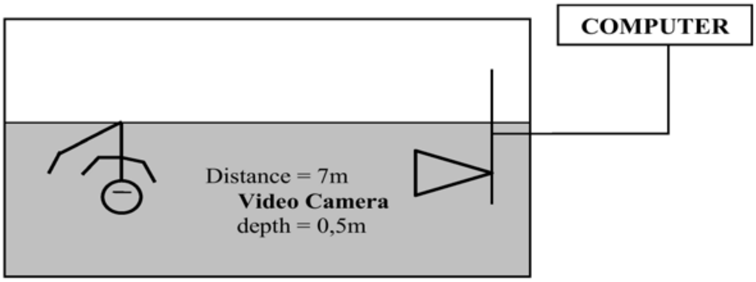

FIGURE 1. Placement of the video camera in relation to the subject

The camera images were then computer processed with the Avi Image software package used for analysis and assessment of movement technique.

In synchronized swimming the judges watch, first of all, for the precision of all figure movements according to the official technical standards. The score is determined by the height and stability of executed positions as well as by maintaining proper angles in synchronized swimming positions. Each constituent position of a figure features specific difficulty parameters.

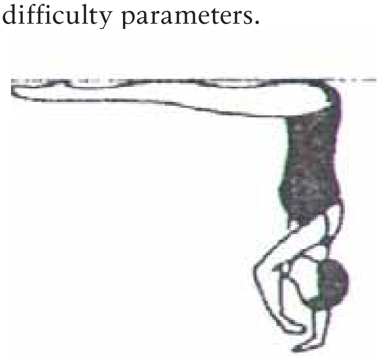

FIGURE 2. Front Pike position according to the official regulations

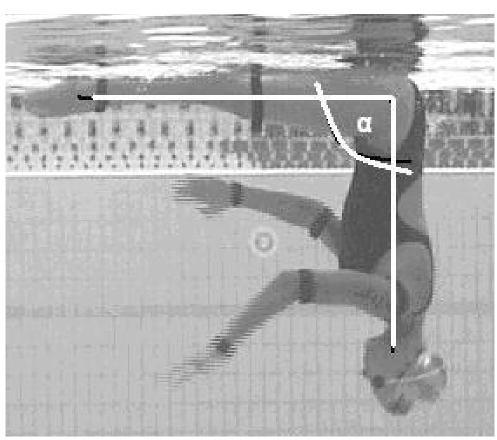

FIGURE 3. Front Pike position according to FINA rules with α angle

The Front Pike is one of the basic positions in synchronized swimming (Fig. 2). It is a component of a number of figures being an intermediate position between Front Layout and transition to Vertical. The basic assessment criterion of the Front Pike (as a component of an entire figure) is the angle between the legs and the trunk, which should be 90 degrees according the FINA rules[8] (www.fina.org).

The Front Pike is also one of first positions taught at the early stages of the training process in synchronized swimming. In the Front Pike the α angle is an angle between the trunk and the legs. The vertex of α is the hip joint axis (Fig. 3).

The Surface Arch is an intermediate position between Back Layout and Vertical (Fig. 4). According to FINA rules, in the Surface Arch position the swimmer's lower back is arched, with the hips, shoulders and head on a vertical line and the legs together and at the surface[9].

A correct Surface Arch execution depends on the swimmer's flexibility. One of components of the judges' score of a swimmer's execution of Surface Arch, is visual evaluation of the swimmer's range of mobility in the joints. It is important that the swimmer maintains the legs straight together on the water's surface. The angle between the trunk and legs must be as close to a 90-degree angle as possible.

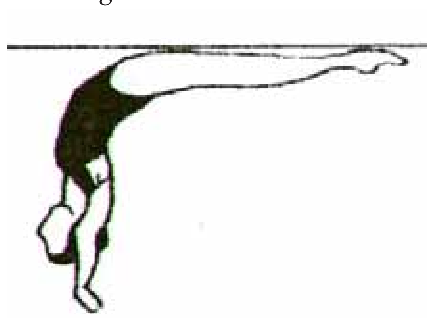

FIGURE 4. Surface Arch position according to FINA rules

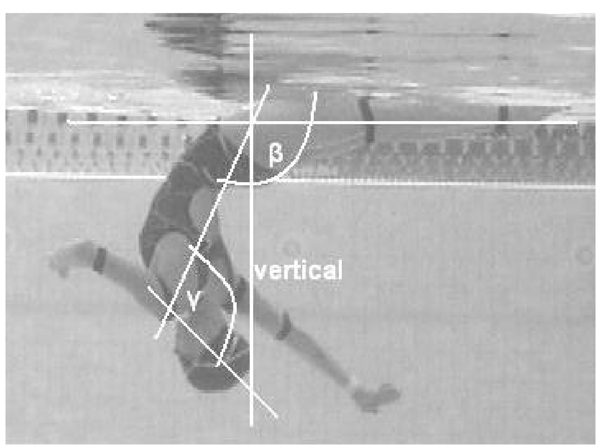

FIGURE 5. Surface Arch position with β and γ angles marked

8 www.fina.org
9 Ibid.

The β angle in the Surface Arch position is an angle between the legs and the trunk; the β angle vertex is the hip joint axis (Fig. 5). The γ angle is an angle between the trunk and the neck-head line running through the ear; the γ angle vertex is the shoulder joint axis (Fig. 5).

The subjects also performed the following tests to determine their selected motor abilities outside the swimming pool:

- a rhythmic coordination test: author's test of 10 upper limb multiple movements in the rhythm of a metronome;
- Ozierecki's static balance test;
- Ozierecki's dynamic balance test;
- flexibility test consisted of: a sit and reach test – legs straddled, right and left astride stand, astride position;
- spatial orientation test[10].

The anthropometric measurements primarily concerned length parameters of the subjects' bodies. It was assumed that swimmers with higher length parameters were more predisposed to synchronized swimming. The measurements included body height, trunk length, upper limb length, arm length, forearm length, lower limb length, thigh length, shank length and foot height.

RESULTS

Tab. 1 lists differences between the actual values of the angle (α) obtained by subjects and the required 90-degree angle.

TABLE 1. The α angle between the trunk and legs in Front Pike in three consecutive measurements

	1st measurement		2nd measurement		3rd measurement	
	α	difference < 90°	α	difference < 90°	α	difference < 90°
Min	83.4	–6.6	86.0	–4.0	92.6	2.6
Max	117.6	27.6	107.6	17.6	114.1	24.1
$\bar{x}$	98.5	8.5	98.7	8.7	100.4	10.4
SD	7.6	7.6	7.4	7.4	5.3	5.3
V	7.7	89.4	7.5	85.1	5.3	51

The results obtained show that synchronized swimmers most often achieved an angle larger than 90°. Considering that a –0.1 difference found in one subject was non-significant, a 90° angle was found in three swimmers. Thus the majority of swimmers, while executing an obtuse angle, did not feel the necessity to bring the trunk closer towards the legs. This can be related to the swimmers' level of flexibility and stretching of the muscles and tendons on the back of the legs and the trunk.

10 Raczek, Mynarski, Ljach, op. cit.

The actual maximum α angle value in the Front Pike amounted to 117.6 in the first measurement. In most subjects who took part in three consecutive measurements, the angles in the second measurement were closest to 90°. In total, the α angle was wider than 100° twenty-two times, which is a highly significant difference.

The lowest α value was 83.4°. This was most likely a result of arm movements performed too far away from the body. Interestingly, both α values (minimum and maximum) were recorded in the first measurement. Only one senior swimmer attained her α value close to 90° in all three measurements. An α angle lower than 90° was only recorded four times.

The mean α value was higher in the consecutive measurements, which indicates that training does not improve Front Pike technique.

TABLE 2. The β angle between the trunk and legs in Surface Arch in three consecutive measurements

	1st measurement		2nd measurement		3rd measurement	
	β	difference ≤ min	β	difference ≤ min	β	difference ≤ min
Min	120.67	4.38	124.64	8.35	116.29	0
Max	146.63	30.34	140.05	23.76	141.76	25.47
$\bar{x}$	132.18	15.89	131.16	14.27	127.93	11.64
SD	6.66	6.66	4.29	4.52	7.21	7.21
V	5.03	41.91	3.27	31.67	5.64	61.94

The β angle (Tab. 2) was the actual angle attained by synchronized swimmers while performing the Surface Arch position (Tab. 2). No subject achieved the β angle even close to the required vertical.

Since the FINA rules do not stipulate the precise β angle which should be achieved by synchronized swimmers, the lowest recorded value of 116.3 arc degrees (by a junior swimmer in the 3rd measurement) was taken as the reference value. Only four other swimmers achieved their β angle close to this reference angle. The largest noted deviation from the reference value was 146.6°.

The mean β angle value decreased in the consecutive measurements, which is indicative of a positive impact of technical training. The degree of the γ angle between the trunk and the neck-head line, determines the conformity of the executed position with FINA rules, which stipulate that the swimmer's hips shoulders and head should be on a vertical line. Thus a model; hips-shoulder-neck-head line should be 180°. However, since the hips were not bent to form a right angle (the trunk was positioned vertically) and the head was inclined forward or backward, the actual angles attained by the swimmers were different from the reference angle (Tab. 3).

Fig. 6 presents three different types of angles of intersection between the trunk line and neck-head line. Out of the 43 images of the Surface Arch position, 8 images showed the "A" angle type, 25 – "B" angle type and 10 – "C" angle type (Fig. 6). None of the swimmers under study attained the required 180° angle; and in none of them the line connecting the hip joint axis, shoulder joint axis and ear was a straight line (not necessarily vertical). The photographs showed that none of the

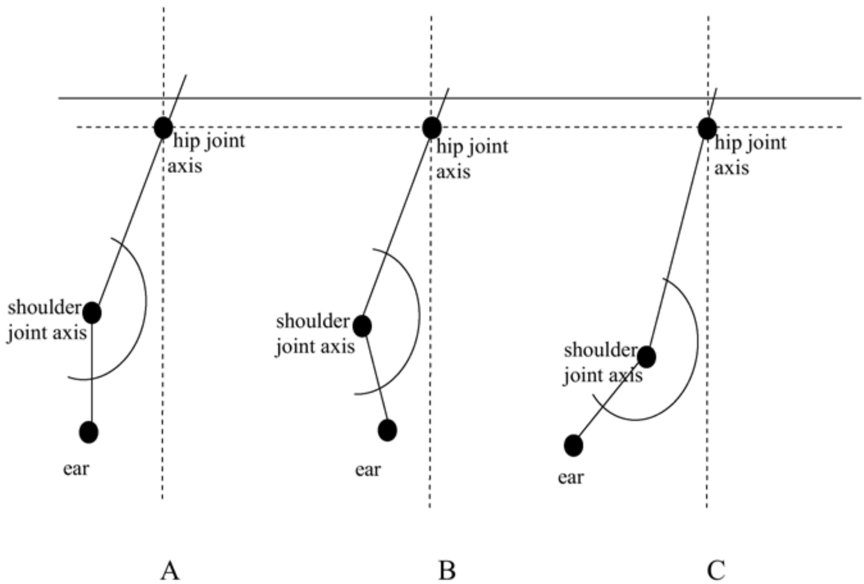

FIGURE 6. Three types of angles of intersection between the trunk line and neck-head (ear) line in synchronized swimmers in the Surface Arch

TABLE 3. The γ angle between the trunk and the neck-head line in the Surface Arch in three consecutive measurements

	1st measurement	2nd measurement	3rd measurement
Min	84.1	104.3	106.3
Max	179.5	179.7	177.9
$\bar{x}$	126.8	129.7	149.7
SD	28.1	22.8	22.4
V	22.2	17.6	15.0

subjects, some of whom were top-level synchronized swimmers, managed to fulfill the FINA requirements concerning the Surface Arch position. The mean values of γ angle (Tab. 3) increased in the consecutive measurements, i.e. the subjects' angle type tendency was from "B" through "A" to "C". The differences between the minimum and maximum γ angle values were fairly wide, which was an indication of differences in subjects' Surface Arch execution. However, the noted low coefficient of variation showed that very few swimmers achieved the extreme values of the γ angle.

Although from the judges' standpoint, the differences in the γ angle in the consecutive measurements can be noted, they were not statistically significant.

The present study also examined correlations between selected elements of movement technique, motor test results and somatic traits in each synchronized swimmer, with the use of Spearman's rank correlation coefficient. The results of statistical analysis are presented in Tab. 4. Only two somatic traits: trunk length and lower limb length, were weakly correlated with the actual angles in Surface

TABLE 4. Statistically significant correlations between age, somatic traits, results of tests outside the pool and movement technique elements determined with Spearman's rank correlation coefficient (R)

Parameter	Technique element		
	α	β	γ
Age		R = –0.5 p = 0.008	R = 0.47 p = 0.035
Trunk length		R = –0.44 p = 0.022	
Lower limb length			R = –0.67 p = 0.049
Shank length			R = 0.85 p = 0.004
Static balance test – right leg in front	R = –0.47 p = 0.015		R = –0.78 p = 0.008
Coordination test			R = 0.51 p = 0.020
Right split			R = 0.73 p = 0.004
Left split		R = –0.41 p = 0.036	
Side split		R = –0.39 p = 0.049	R = 0.73 p = 0.016

TABLE 5. Statistically significant differences between groups of subjects with different levels of coordination and flexibility skills

Statistics	Parameters	
	age	β
Kruskal-Wallis one-way analysis of variance	6.6	8.9
p-value	0.037	0.012

Arch attained by the swimmers. A strong correlation was, however, found between swimmers with long shanks and a large γ angle ("C").

The obtained results revealed that the smallest β angle was achieved by older swimmers (Tab. 5) with longer trunks, who can successfully execute a left split and a side split (Tab. 4). It can be concluded that swimmers with a high level of hip joint mobility can execute better synchronized swimming positions, which require a great degree of flexibility, such as Surface Arch.

The closest α angle to the model angle in the Front Pike was achieved by swimmers who scored high in the static balance test; however the angle was only correlated with the results of the static balance test with the right leg in front. Most correlations were found between the remaining test results and the γ angle (Tab. 4).

The statistical analysis also concentrated on differences between parameters in synchronized swimmers divided into three skill-level groups on the basis of their coordination and flexibility test results:

1. top-level skills (N = 8);
2. medium-level skills (N = 9);
3. low-level skills (N = 9).

The Kruskal-Wallis one-way analysis of variance revealed a statistically significant difference in age and β angle between the top-level skills group and low-level skills group.

The results of the Kruskal-Wallis test pointed to a low significance of tested coordination and flexibility skills for movement technique in the water.

DISCUSSION

The Front Pike is a position learnt by synchronized swimmers after acquisition of the basic movement techniques in the water. In the present study the majority of synchronized swimmers attained a larger Front Pike angle, than the 90° angle required by the FINA. Out of three consecutive measurements, the subjects achieved their Front Pike angles closest to the FINA model, in the second measurement. This could have been related to the schedule of these measurements as the 1st and 3rd measurements were taken before and after the competitive period, respectively, while the 2nd measurement, during the competitive season, i.e. the time during which the subjects' prepared to achieve the highest sports results. The Front Pike angle was only correlated with the results of the static balance test: the better the static balance test result, the smaller the α angle. These results correspond to Starosta's conclusion that in technical sports, the most precise recreation of movement can be observed during the competitive period[11].

The results of statistical analysis shows a weak correlation between elements of movement technique, motor test results and somatic traits. A number of other authors show that coordination test results, often in the same subjects, reveal weak correlations with the execution of movements in sports requiring high-level coordination skills[12]. A similar observation was made in the present study: the correlations were few and weak, despite their statistical significance.

The FINA rules do not specify the correct angle between the trunk and the legs in the Surface Arch position. However, they stipulate that the swimmer's ears, shoulders and hips should form a vertical line. Thus the angle in Surface Arch, as in the Front Pike, should be close to 90°. The ideal execution of this position is rather difficult. This difficulty was once referred to by the famous Hungarian coach, Gabor Snaouder. While at the International Coaching Conference in Bonn, in 2006, Snaouder duly observed that, "the majority of positions, figures and technical elements are invented by people who have no idea about the actual human abilities to execute them."

In the present study only older swimmers with longer trunks were able to execute the Surface Arch position close to the model. The γ angle in the Surface Arch seems to compensate for the less attainable β angle. In the Surface Arch, the neck and the head, control and balance the execution of the entire position.

11 Starosta, op. cit.

12 Iskra J., The ability to perform rhythm and results of selected dexterity tests in a group of the best Polish hurdlers [in Polish], *Trening*, 1999, no. 11, pp. 56–64.

None of the subjects in the present study were able to execute the Surface Arch position as described in FINA regulations. The obtained results justify Gabor Snaouder's observations, and the present study's aim. A Front Pike model execution is therefore far more achievable than a Surface Arch execution.

CONCLUSIONS

1. The angle between the trunk and the legs in the Front Pike position was too large in most subjects. The angle was hardly correlated with subjects' test results and somatic traits.
2. The angle between the trunk and the legs in the Surface Arch position was too large in all subjects. Its execution was not even close to the FINA requirements.
3. The angle between the trunk and the legs in the Surface Arch position was correlated with the results of flexibility and coordination tests.
4. The angle between the trunk line and the neck-head line control and balance the Surface Arch position and its execution depends on a swimmer's age, experience, body build and physical fitness.
5. The FINA requirements regarding the Surface Arch position are far too stringent.

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Biomechanical analysis of errors in monofin swimming technique – didactical implications

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INTRODUCTION

From the biomechanical point of view, the technique of monofin swimming can be defined as a kind of locomotion in water, based on the oscillatory movements of the trunk and legs in the sagittal plane, while in a prone position. The scope of movement increases, from the shoulders in the direction of the centre of the swimmer's mass and feet, which transfer torque to the surface of the monofin, which is regarded as the main source of swimmer propulsion[1]. The sporting aim of monofin swimming is to achieve the maximum speed over a racing distance.

The surface of a monofin is about twenty times larger than the propulsive surfaces used in traditional swimming. Hence, the general belief that the fin supports swimming. This is true when a monofin or a pair of traditional fins are treated as a tool in the perfecting of locomotion in water as well as a source of propulsion in scuba diving or in lifesaving. The specific nature of monofin swimming, because of the water resistance acting against the large surface of the monofin, makes it difficult for swimmers to perform movements without prior motor experience. Therefore, the non-sporting aim of monofin swimming technique seems to be the skill of using the monofin for efficient and economical propulsion. In this context monofin swimming for learning, leisure or water rescue requires basic technical ability. At a championship sporting level, a perfect technique is required, as the monofin does not "forgive errors".

The explicit conditions generating propulsion during monofin swimming have inspired several multidirectional biomechanical analyses of technique. A description of the processes of propulsion generation by the monofin were the aim of studies conducted by, e.g. Colman et al.[2] and Ungerechts[3]. Several criteria de-

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1 Rejman M., Colman V., Persyn U., The metod of assessing the kinematics and dynamics of single fin movements, *Human Movement*, 2003, vol. 2, no. 8, pp. 54–62.

2 Colman V., Persyn U., Ungerechts B.E., A mass of water added to swimmer's mass to estimate the velocity in dolphin-like swimming bellow the water surface, [in:] Keskinen K., Komi P., Hollander A. (eds.), Biomechanics and Medicine of Swimming VIII, Gummerus Printing, Jyväskylä, 1999, pp. 89–94.

3 Ungerechts B.E., A comparison of the Movements of the Rear Part of Dolphins and Butterfly Swimmers, [in:] Hollander P.A., Huijing G. de Grot (eds.), Biomechanics and Medicine in Swimming. International Series of Sport Science. Human Kinetics, Champaign, 1982, pp. 215–221.

scribing the quality of monofin swimming technique were estimated[4]. In order to search for a direction towards the development of monofin swimming technique, in optimization of biomechanical parameters, several forms of modeling were developed[5]. The remaining analyses are set aside for the purposes of application – useful in the training process[6]. Therefore, the biomechanical methods and tools used in this study are understood as quantifiable factors in the gaining of an educational aim – the development of a quality monofin swimming technique.

The idea of brining together biomechanical and educational objectives can be realized through sequential movement analysis[7]. Movement sequencing, from a biomechanical point of view, allows the partition of movements into their smallest fragments resulting from the mutual positioning of body segments in motion. The educational justification for a sequential partition of swimming movement structure, stems from the possibility to precisely name the fragments of a defined movement. This ability to verbally name a particular movement allows the combining of cognizant execution of action, with the perception of what this action should be, supporting the intellectual process of teaching and perfecting technique[8]. From a biomechanical point of view an error may objectively be defined as an execution of movement not in accordance with the pattern. From an educational perspective, it may be a movement not in accordance with the original

4 Nicolas G., Bideau B., A kinematic and dynamic comparison of surface and underwater displacement in high level monofin swimming, *Human Movement Science*, 2009, vol. 28, no. 4, pp. 480–493; Rejman, Colman, Persyn, op. cit.; Shuping L., Hong Y., Luk T., The power initiating point and tail vortex in scuba swimming, [in:] Hong Y., Johns D.P. (eds.), Proceedings of XIII International Symposium on Biomechanics, Press of Chinese University of Hong Kong, Hong Kong, 2000, pp. 289–292; Shuping L., Sanders R., Mechanical properties of the fin, [in:] Gianikellis K. (ed.), Scientific Proceedings of XX International Symposium on Biomechanics in Sports, Caceres, 2002, pp. 479–481; Yi-Chung P., Hay J., A hydrodynamic study of the oscilation motion in swimming, *International Journal of Sport Biomechanics*, 1988, no. 4, pp. 21–37; Rejman M., Dynamic criteria for description of single fin swimming technique, [in:] Keskinen K.L., Komi P.V., Hollander A.P. (eds.), Biomechanics and Medicine of Swimming VIII, Gummerus Printing, Jyväskylä, 1999, pp. 171–176.

5 Wu Yao-Tsu T., Swimming of waving plate, *Journal of Fluid Mechanics*, 1968, no. 10, pp. 321–344; Matsuuchi K., Hashizume T., Nakazawa Y., Nomura T., Shintani H., Miwa T., Flow visualization of unsteady flow field around a monofin using PIV, [in:] Vilas-Boas J.P., Alves F., Marques A. (eds.), Xth International Symposium Biomechanics and Medicine in Swimming, *Portuguese Journal of Sport Sciences*, 2006, vol. 6, suppl. 2, pp. 60–62; Miwa T., Matsuuchi K., Shintani H., Kamata E., Nomura T., Unsteady flow measurement of dolphin kicking wake in sagittal plane using 2C-PIV, [in:] Vilas-Boas J.P., Alves F., Marques A. (eds.), Xth International Symposium Biomechanics and Medicine in Swimming, *Portuguese Journal of Sport Sciences*, 2006, vol. 6, suppl. 2, pp. 64–66.

6 Rejman M., Wiesner W., Single Fin Swimming Technique as the Teaching Aim and the Subject of Teaching Evaluation, [in:] Petriajev I., Klieszewa W. (eds.), "Swimming Training Hydrorehabilitation" OOI Pławin, Petersburg, 2003, pp. 106–110; Rejman M., Ochmann B., Modeling of monofin swimming technique: optimization of feet displacement and fin strain, *Journal of Applied Biomechanics*, 2009, no. 25, pp. 340–350; Persyn U., Colman V., Zhu J.P., Scientific concept and educational transfer in undulating competitive strokes in Belgium, *Koelner Schwimmsporttage 1996*, Sport-Fahnemann-Verlag, Bockenem, 1997, pp. 34–40.

7 Czabański B., Selected issues in teaching sport technique [in Polish], AWF, Wrocław, 1989.

8 Meinel K., Schnabel G., Bewegungslehre Sportmotorik (Abriss einer Theorie der sportlichen Motorik unter pädagogischem Aspekt), Meyer & Meyer, Koeln, 2007.

intention[9]. The nature of the goals in the above definition may stem from the fact that an objective interpretation of technical assessment, in the biomechanical sense, is not always sufficient in the realization of subjective educational aims. While on the other hand, information on the dynamic and kinematic technical structures of movement, assist the process of physical education in sport via the intellectualization of technical training[10].

Therefore, the cognitive aim of this study is the identification of error in the movement structure of the legs and monofin, reducing the technical quality of swimming, and making impossible the achievement the maximal swimming speed. For the realization of the practical aims (i.e. application the biomechanical tools for educational aspects of assessment of monofin swimming technique), the following research assignments were formulated: (1) identification of errors in the structure of leg and monofin movement, in order to describe their structure and scale; (2) identification of key technical elements of leg and monofin movement in terms of potential errors with an aim towards their anticipation and elimination; (3) identification of the relation between monofin swimming speed and the structure and scale of errors, with an eye towards the minimization of error, and for use as criteria in technical analysis of monofin swimming quality.

METHODS

Six males – representatives of the Polish Monofin Swimming Team, voluntarily took part in the research. The characteristics of the participants (Tab. 1) allows the assumption that they constituted a homogenous group in terms of age and somatic parameters. The fact that they belong to the national team, seems to give evidence of their high level of monofin swimming proficiency.

TABLE 1. Characteristics of monofin swimmers participating in the study (SD – Standard Deviation)

Subjects	Ages	Body high (m)	Body mass (kg)
A	15	1.75	70
B	16	1.71	64
M	15	1.63	64
N	16	1.65	52
P	18	1.80	73
S	17	1,93	84
Average	**16.17**	**1.75**	**67.83**
SD	**1.17**	**0.11**	**10.70**

9 Bremer D., Sperle N. (eds.), Fehler, Mangel, Abweichungen im Sport, [in:] Schriftenreihe des ADH "Sport & Lernen", Putty, Wuppertal, 1984, pp. 107–119.

10 Schmidt R.A., Lee T.D., Motor Control and Learning. A Behavioral Emphasis, Human Kinetics, Champaign, 2005.

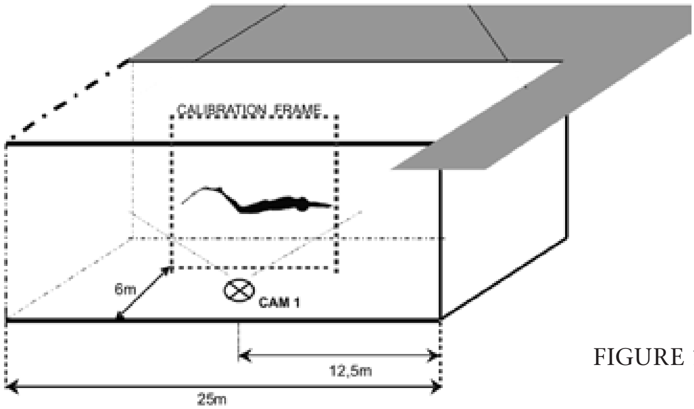
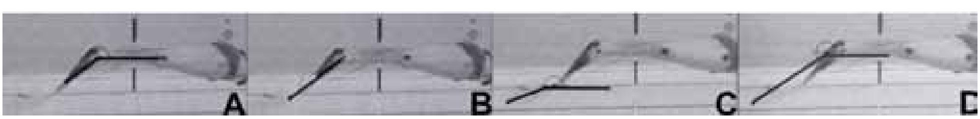


FIGURE 1. General description of experimental setup

Swimmers conducted a progressive test (swimming 900 m underwater at increasing speeds so that the last part of the distance was swum at the subjectively assessed maximal speed). The trial distances were divided into 300 m parts. Swimmers took a 180 s break after swimming each part of the trial distance. This construction of progressive tests was adapted for monofin training from training in traditional swimming[11]. Swimmers swam individually on the water's surface, using their own monofins, in a short course pool.

In order to record the parameters describing leg and monofin movements – swimmers were filmed underwater. The digital camera was stable and located in the middle of the pool. Based on the assumption that the movement of swimmer and monofin act in a saggital plane[12], the location of the camera was chosen so as to hold the largest possible image of the swimmers in frame, over more than the entire cycle[13] (Fig. 1). The axis of the lens was perpendicular to the objects filmed. The recording frequency was 50 Hz.

Markers, allowing for the tracking of displacement of particular segments of the legs, were applied to the bodies of the swimmers. Points were located on both sides of the axes of the ankle, knee and hip[14] (Fig. 2).



A – Angle of flexion of the ankle in relation to the shin (KAT); B – angle of flexion of proximal part of the fin in relation to the feet (ATM); C – angle of attack of distal part of the fin (HME); D – angle of attack of the entire surface of the monofin (HTE)

FIGURE 2. Examples illustrating procedure for defining angles of flexing of leg segments and monofin and based on points marked on the axes of joints and monofin

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11 Maglischo E.W., Swimming Fastest, Human Kinetics, Champaign, 2003.
12 Rejman, Colman, Persyn, op. cit.
13 Rejman, Ochmann, op. cit.
14 Plagenhoef S., Patterns of Human Motion – a Cinematographic Analysis, Prentice-Hall, Englewood Cliffs, 1971.

The monofin was also marked at the tail (where the plate is joined to the foot), at the middle and at the edge of the fin. The marks served to divided the fin into proximal (between tail and middle) and distal (between middle and edge) parts, as well as to monitor the entire surface of the fin (Fig. 3).

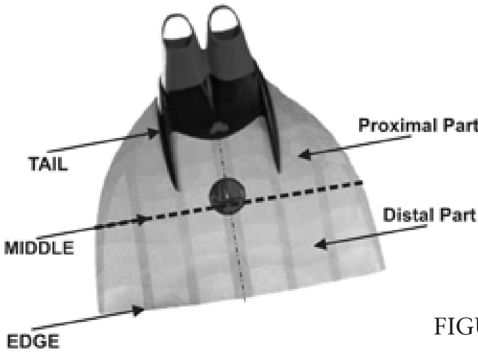


FIGURE 3. Division of the surface of the monofin

A kinematic analyses of leg and monofin movement were conducted using the SIMI motion analysis system. A random cycle (every 100 m) from each swimmer was chosen for analysis. The results were obtained in the form of temporal signals for the angles of bend at the foot in relation to the shank (KAT), the proximal part in relation to the foot (ATM), the angle of attack of distal part (HME) and the angle of attack of entire surface of the monofin (HME) (Fig. 4). The average horizontal velocity of the center of the swimmer's body mass was also estimated.

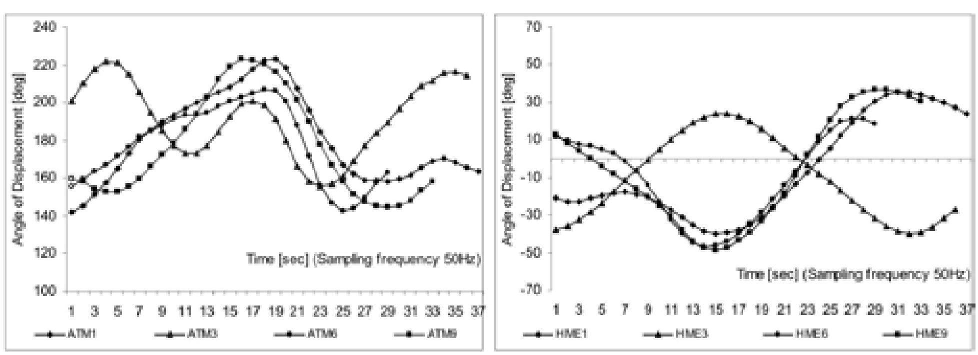


FIGURE 4. Examples of a temporal series illustrating the fluctuation of the analyzed angles of foot flexion (ATM) and the angles of bend and angles of attack of distal part monofin (HME)

The choice of parameters was based on a previously devised functional model of monofin swimming. The advantage of this model is the optimization of chosen (and objectively recognized as most relevant) parameters of leg and monofin movement in order to achieve maximal swimming speed[15]. The study citied specified the optimal range of foot flexion in relation to the shin (KAT) and show that,

[15] Rejman, Ochmann, op. cit.

a limitation of movement to around 160° (–20°) from the perpendicular location against the shin (180°), plays an important role in the achievement of maximal swimming speed. During downward phase the limitation of plantar flexion of the feet should not exceed 180°. An optimal bending of the proximal part of the monofin in relation to the feet (ATM), in order to achieve maximal speed, was estimated at 35° in downward movement and (–27°) in upward. The model range of the angles of attack of the distal part of the fin (HME) and its entire surface (HTE) are located in a range between 37° in downward phase and (–26°) in upward movements.

ANOVA Friedman's test and Kendall's coefficient, useful in analysis of small groups (n = 9), confirmed the existence of similarities in the data studied. The results of Friedman's test for trials preformed for each swimmer, showed a significant statistical differentiation (p = 0.005) for all angular parameters studied. The mean value of Kendall's coefficient, also estimated for trials preformed for each swimmer, was 0.79630.

In the first stage of analysis, the range errors committed by swimmers in relation to the model, were mapped. A basis for the analysis was created by the value of the angular parameters examined in a time function of the cycles analyzed (while swimming 100 m, 300 m, 600 m, and 900 m of trial distances) (Fig. 5).

The errors were quantified by calculating the areas of the fields estimated on the basis of the range of the angles analyzed, which exceeded (or did not attain) the boundary established by the model (Fig. 5). The value of fields estimated in a given cycle were totaled for each of the participants tested. In the next stage, the estimated range of errors were illustrated by the movement sequence registered before. These sequences were compared with sequences which achieved the criteria of the model, or demonstrated a slight comparable difference. The procedure described, delivered information concerning the scale of the errors during movements, and the structure of the errors in comparison with the stated model, by all swimmers in the cycles analyzed. This procedure also allowed for the identifica-

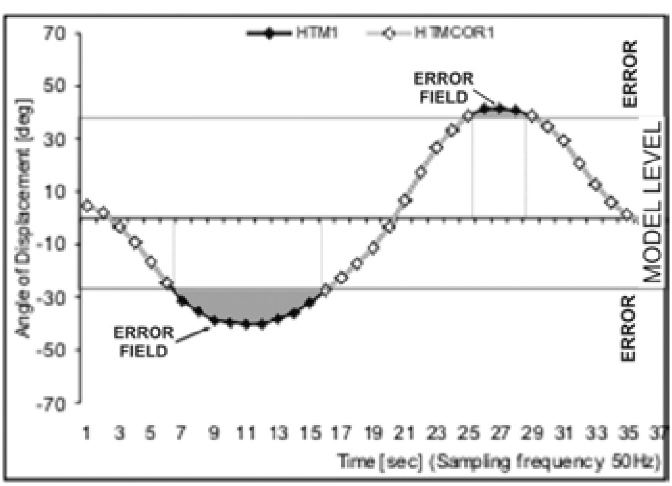


FIGURE 5. Example of quantification of errors registered in angular displacement of the parameters studied

tion of movement sequences that estimated the interval of erroneous positioning of the segments of the leg and monofin in comparison with the assumed model. Identification of the sequences mentioned, in association with the result of the analysis of the scale and structure of the errors, allowed for the separation of the key elements of leg and monofin movement structure, with regard to the probability of committing errors. The illustration and the outcome of the procedures mentioned are presented as results in the appropriate section of this study. Knowledge about the sources of potential error, effecting a decrease in swimming quality, contains an important implicational value.

In the next part of the analysis, the relationship between objectively estimated errors and horizontal swimming velocity, were researched. To this end, a correctly recorded series of analyzed angular parameters (in time function) were juxtaposed together with a series of horizontal swimming velocities, in the same cycles. Person's correlation coefficients between the values of errors made by swimmers in consecutive cycles (at distances of: 100 m, 200 m, 300 m, 400 m, 500 m, 600 m, 700 m, 800 m, 900 m) and the average horizontal swimming velocity gained by the swimmers, while swimming particular sections, were estimated.

The great volume of the results obtained, necessitated the reduction of their presentation. With an intention to present a cross-section of results, examples of trials conducted by swimmers are illustrated by those who obtained the highest average speed, and those who swam the trial distance most slowly.

RESULTS

The scale of errors concerning the angle of flexion of the feet in relation to the shanks, estimated for the swimmers performing most slowly (N) was lower, in comparison to errors committed by swimmers recording the highest average speed (M) (Fig. 5, Tab. 2). Errors performed by the fastest swimmers were related to excessive plantar flexion of the feet in downbeat and excessive dorsal flexion of the feet in upbeat. Subjects swimming at the slowest average speed showed excessive plantar flexion of the feet in the downbeat. While in the upbeat, dorsal flexion of the feet, fluctuated below the values designated in the model.

Errors related to flexion of the feet in relation to the shanks (Fig. 6, Tab. 1) occurred in the fastest swimmers (M), between initiation of downbeat phase (the

TABLE 2. Sum of errors committed by fastest (M) and slowest (N) swimmers compared to average value calculated for all swimmers

	Sum of errors (%)			
Parameter	M	N	average	SD
KAT	58	65.7	71.5	8.4
ATM	27	43	34.6	6.1
HME	29.8	47.2	34.6	6.1
HTE	22.4	49.4	42.5	8.5

KAT – angle of flexion in foot at ankle joint; ATM – angle of bend in tail of monofin
HME – angle of attack of distal part of fin; HTE – angle of attack of entire surface of fin

legs flexed maximally at knee joints, monofin segments positioned parallel to each other – sequences: M9-4, M1-4, M3-24) and its finish (the legs extended at knee joints, the feet in their deepest position in the cycle, the tail at maximal bend, together with the maximal angle of the entire surface of monofin – sequences: M9-16, M17-4, M3-33). Errors committed in the upbeat occurred during elevation of the legs, just before the beginning of their flexion in the knees, together with maximal bending of the monofin in the middle of its surface (sequences: M9-20, M6-5, M1-19). These errors were recorded up to the finish of this movement phase, when the feet gained their deepest position, together with maximal angle of attack of the entire surface of the monofin (sequences: M9-30, M6-29, M1-33).

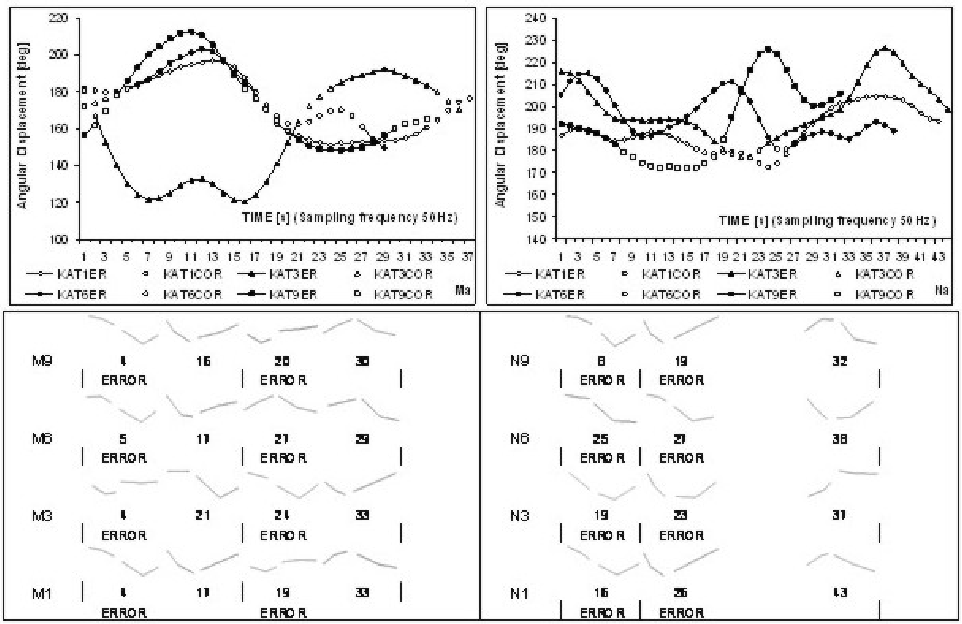


FIGURE 6. Sample graph illustrating scope of errors (black dots – ER) in angle of foot flexion in relation to shank (KAT) in time function (for separate cycles registered at 100 m, 300 m, 600 m, 900 m). Below are movement sequences illustrating the range of errors compared with model, shown in the graph as fastest (M) and slowest (N) swimmers

The swimmer who recorded the slowest speed (N), committed errors during almost the entire upbeat (sequences: N9.19-32, N3.23-37, N1.26-43). Errors registered in downbeat were, as in the case of the fastest swimmer, at the initial segments of these phases (sequences: N9-8, N6-25 and 27-38, N3-19, N1-16).

An analysis of errors related to bending of the proximal part of the fin in relation to the feet (Fig. 7, Tab. 1), show that the slowest swimmer (N) committed more of these in comparison to the fastest swimmer (M). In both swimmers, errors in relation to the model, occurred as excessive bending of the proximal part of the fin, in both movement phases. Moreover, the fastest swimmer strongly bent the tail of the fin in the second part of the upbeat, while the slowest swimmer strongly bent the tail in the second part of the downbeat.

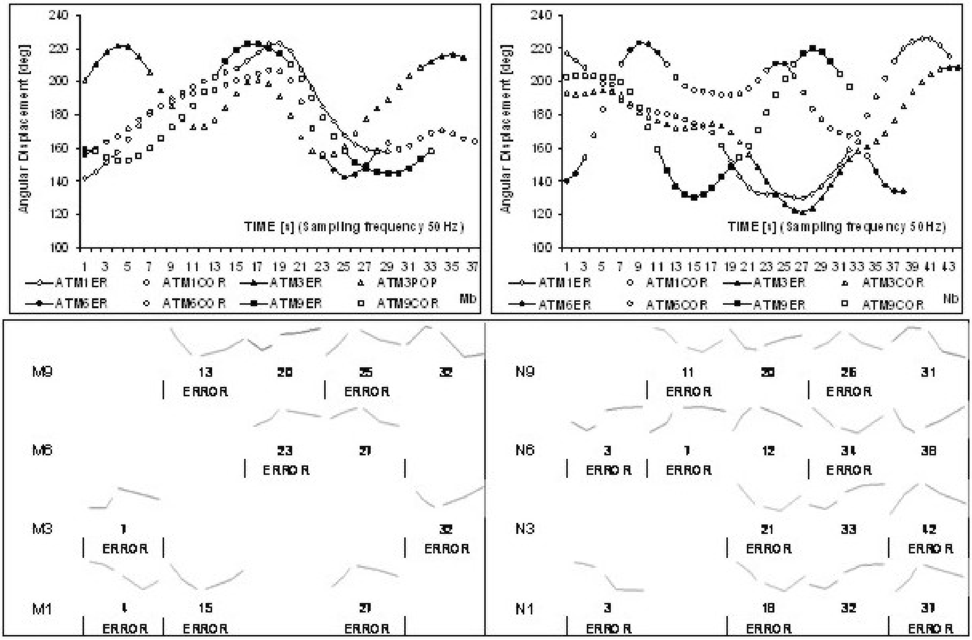


FIGURE 7. Sample graph illustrating scope of errors (black dots – ER) in angle of bend on the proximal part of the fin in relation to foot (ATM) in time function (for separate cycles registered at 100 m, 300 m, 600 m, 900 m). Below are sequences of movement illustrating the range of errors compared with the model, shown in the graph for fastest (M) and slowest (N) swimmers

In the case of the swimmer recording the fastest trial distance, a small range of errors were related to angular bending of the proximal part of the fin in relation to the feet, in downbeat. As is the case in angular flexion of the ankle joints, errors were recorded during the initiation of the phase (sequences: M9-32, M1-4) and at its finish (sequences: M9-13, M3-32, M1-15). During upbeat, errors were considerably more common and were related to initiation – lifting of the legs up to the moment preceding flexion of the knee joints, before maximal bending of the monofin at the middle (sequence: M9-20). Errors in the structure of movement lasted just as long as in the case of angular foot flexion in the ankle joints, i.e. until the finish of the upbeat (sequences: M9-25, M1-27).

The slowest swimmer committed errors while straightening the legs at the knee joints (downbeat). These were observed in the following divisions: from the moment of maximal leg flexion and maximal angular bending of the entire surface of the fin (sequences: N9-11 and 31, N3-21, N6-34, M1-18) until the finish of the downbeat, and continuing to the initiation of upward movement (sequences: N9-20, N6-38). In the upbeat, the range of errors is greater and consists of similar boundaries as registered in the fastest swimmer (from sequences N6-3, N3-33 and N1-32 to sequences N6-12 and N3-42).

An analysis of the angle of attack of the entire surface of the fin (Fig. 8, Tab. 1) shows, as in the case of the parameters currently under examination, that the slowest swimmer (N) committed more errors in relation to the accepted model,

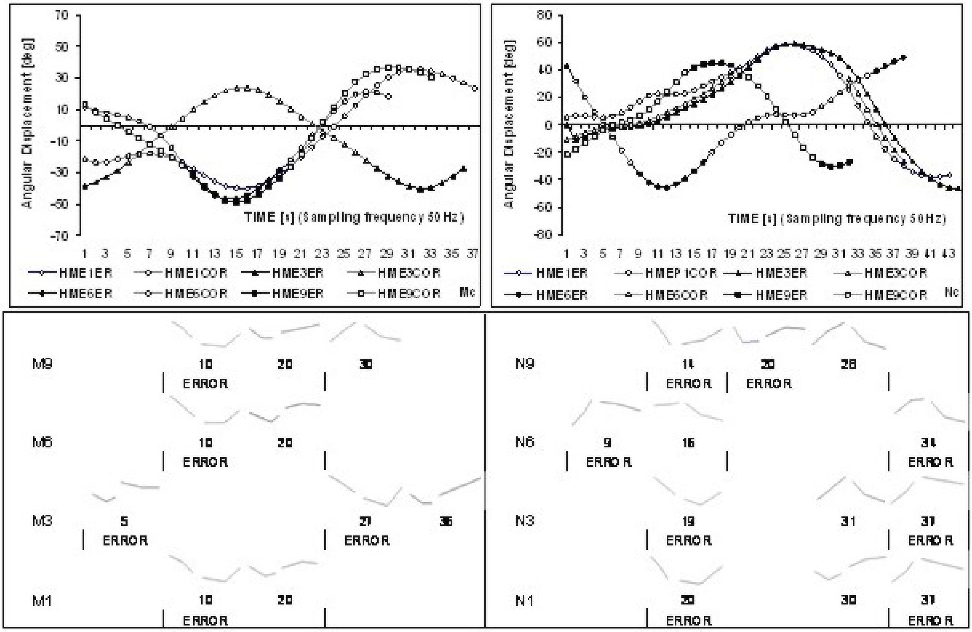


FIGURE 8. Sample graph illustrating scope of errors (black dots – ER) in angle of attack of the distal part of the fin (HME) in time function (for separate cycles registered at 100 m, 300 m, 600 m, 900 m). Below are sequences of movement illustrating the range of errors compared with the model, shown in the graph for fastest (M) and slowest (N) swimmers

than the fastest swimmer (M). Worth noting is the fact that this swimmer performed errors in both movement phases (mainly during upbeat) while the swimmer recording the highest average speed, committed errors only during upbeat. In both swimmers the errors originated from an excessive bend of the distal part of the fin in relation to the model.

The range of errors registered during the trials of the fastest swimmer occurred in the initiation fragment of the middle part of the downbeat – the shanks placed almost parallel to the direction of swimming and the surface of the fin nearly flat in the maximal angle of attack (sequences: M9-10, M3-21, M6-10, M3-27, M1-10). The erroneous movement structure lasted until the middle part of the upbeat – legs straightened at the knees and the monofin bent in its middle to almost the maximal (sequences: M9-20, M6-20, M3-36 M1-20).

The errors committed by the slowest swimmer (as with the swimmer covering the distance fastest) began no earlier than the middle of the downbeat (sequences: N9-14, N3-19 N1-20). The errors blocking movement structure took place throughout most of the upbeat (sequence: N9-20, N1-30), a little less in the finish of the phase, where the feet achieved the maximal upward position and at the maximal angle of attack of the entire surface of the fin (sequences: N9-28, N6-9 and 34, N3-31 and 37, M1-37).

In both swimmers, errors in relation to the accepted model, resulted due to an excessive angle of attack of the whole surface of the monofin (Fig. 9, Tab. 1). The

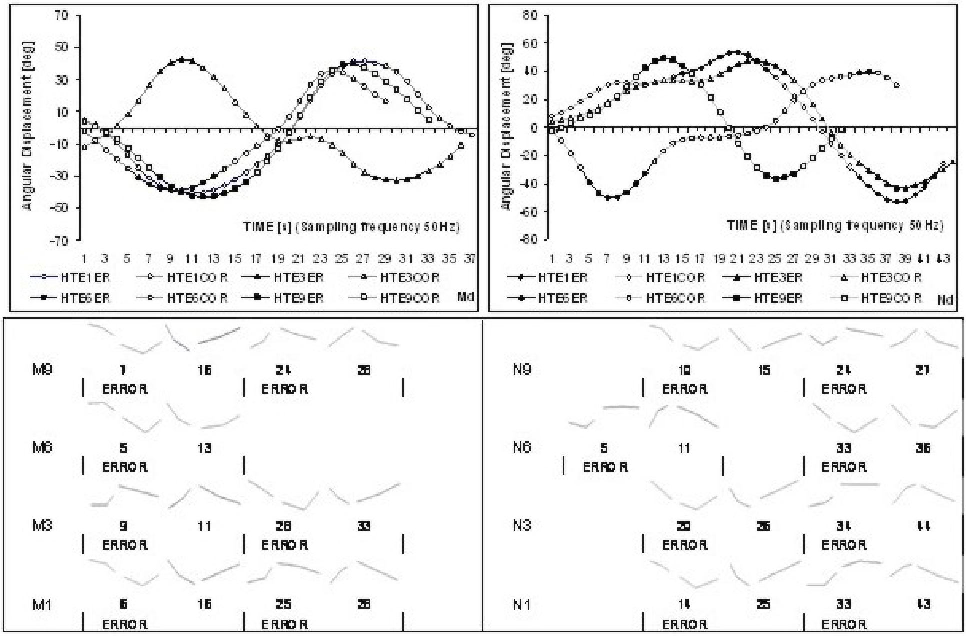


FIGURE 9. Sample graph illustrating scope of errors (black dots – ER) in angle of attack of the entire surface of the fin (HME) in time function (for separate cycles registered at 100 m, 300 m, 600 m, 900 m). Below are sequences of movement illustrating the range of errors compared with the model, shown in the graph for fastest (M) and slowest (N) swimmers

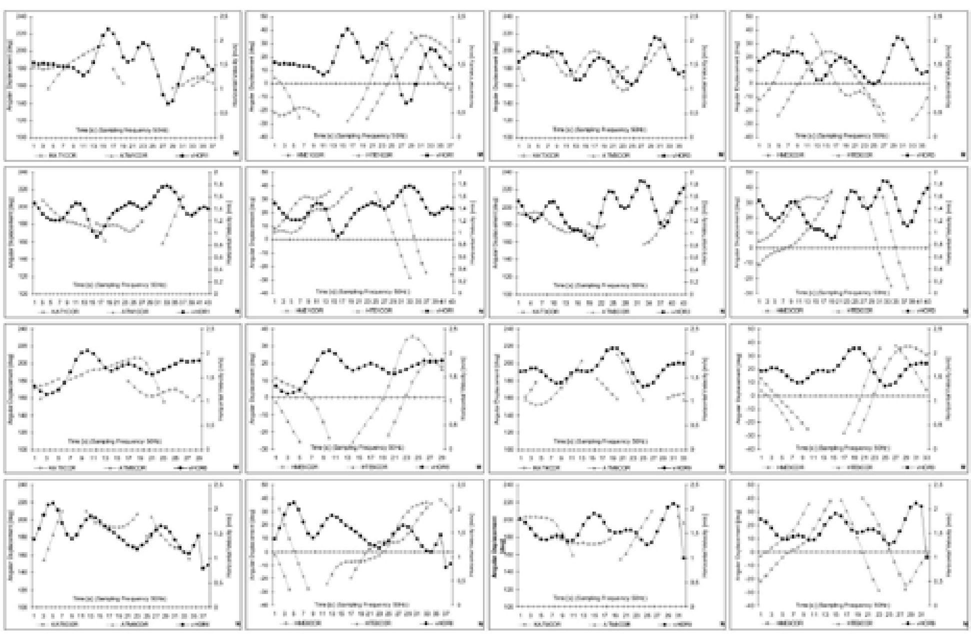
range of errors is higher in the swimmer who swam the trial distance more slowly (N). The results of both swimmers show a similar error structure. Errors occurred in both the upbeat and downbeat phases. Although the fastest swimmer made fewer errors in downbeat.

In the case of the swimmer who achieved the highest average speed, two ranges of error arose. These concerned the angle of attack of the entire surface of the fin. The first took place between the second part of leg extension and full extension, i.e. the finish of the downbeat (sequences: M9.7-16, M6.5-13, M3.28-33, M1.6-16). The second range, beginning in the second part of leg extension at the knees, lasted until the finish of the upbeat, i.e. the moment when the legs achieved their extreme upward position (sequences: M9.24-28, M3.9-11, M1.25-28).

The structure of errors committed in the downbeat was similar for the fastest and the slowest swimmers (sequences: N9.10-15, N6.33-36, N3.20-26, N1.14-25). The differences occurred in errors committed in the upbeat (the legs are at full extension at the knees and the fin is at maximum flexion in the middle part of its surface). The error in movement structure lasted until the finish of the phase, i.e. the upward lifting of the legs while fully extended at the knees, therefore creating a maximal angle of attack for the whole surface of the monofin (sequences: N9.24-27, N6.5-11, N3.34-44, N1.33-43).

The following information related to the structure and scale of errors committed by swimmers in relation to the accepted model was formulated in general:

(1) The swimmer achieving the maximal speed compared to the one achieving the lowest, committed fewer errors described as – changes of the angular flexion of feet at the ankle, changes to the bending of the tail of the monofin and changes to the angle of attack of the distal part and entire surface of the monofin. This tendency is particularly visible during the upbeat. (2) Errors committed by both swimmers occurred as excessive – exceeding the limits established in the model – angular displacement in the segments of the body and monofin under examination. An exception may be errors related to the execution of dorsal flexion of the feet, in the upbeat, lower than the values set forth in the model. Such occurrences were noted in the swimmer recording the lowest trial speed. (3) On the basis of a sum of errors committed by the swimmers, and assuming that the level of errors expressed by the results discussed is a measure of the relative difficulty in realizing the movement structure established in the model; we can assume that the most difficult element of monofin swimming technique is proper range of movement in the ankle joints. Furthermore, we can mention the maintenance of a proper range of angle of attack of the entire surface of the monofin, as well as its proximal and distal segment, while noting that in the above mentioned angles, the level of error occurrence is almost identical. (4) An analysis of the differences in percentage values of errors committed, shows that the parameter most differentiating the

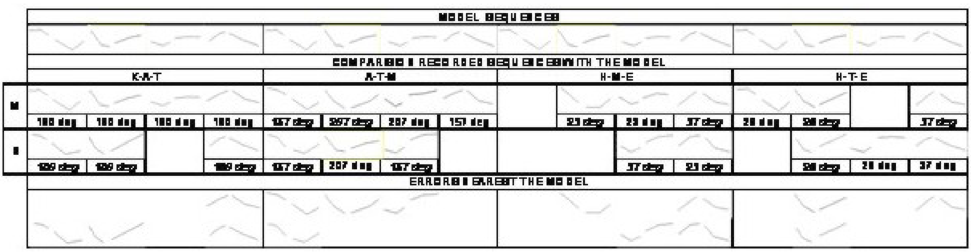


KAT – angle of flexion in foot at ankle joint; ATM – angle of bend in tail of monofin
HME – angle of attack of distal part of fin; HTE – angle of attack of entire surface of fin

FIGURE 10. Sample illustrations of layout of proper movement (COR) in terms of changes analyzed in leg segments and monofin, in relation to horizontal swimming velocity (HOR). Pearson's correlation coefficients between value of error in cycle made by all subjects on 100 m sections, and average velocity (ranked by average velocity)

fastest and slowest swimmers, was angular flexion of the feet in relation to the shanks (KAT) (19.5%). The second parameter in order of importance was the angle of attack for the distal part of the fin (HTM) (11.5%). The differences between the values of errors committed by the swimmers in relation to angular bending of the proximal part of the fin (ATM) (7.3%) and the angle of attack of its entire surface (HTE) (6.8%) was the lowest and most similar.

A graphic layout of the properly executed fragments of the cycle in terms of horizontal swimming velocity (Fig. 10), shows that the errors committed were related to those fragments of the cycle, in which the swimmer's intracycle velocity was almost at maximum.



M – results of the swimmer who swam fastest; N – the results of the swimmer who swam slowest; KAT – angle of the feet flexion in the ankle joint; ATM – angle of bend the monofin's tail; HME – angle of attack of the distal part of the monofin; HTE – angle of attack of the entire surface of monofin

Sequences in accordance to their corresponding model are represented in bold.

Sequences with no significant difference in relation to the model are in italics.

FIGURE 11. A comparison of model movement sequences with recorded sequences, which met the criteria of the model. The sequences presented below were separated from recorded ones as illustrating errors concerning the model sequences

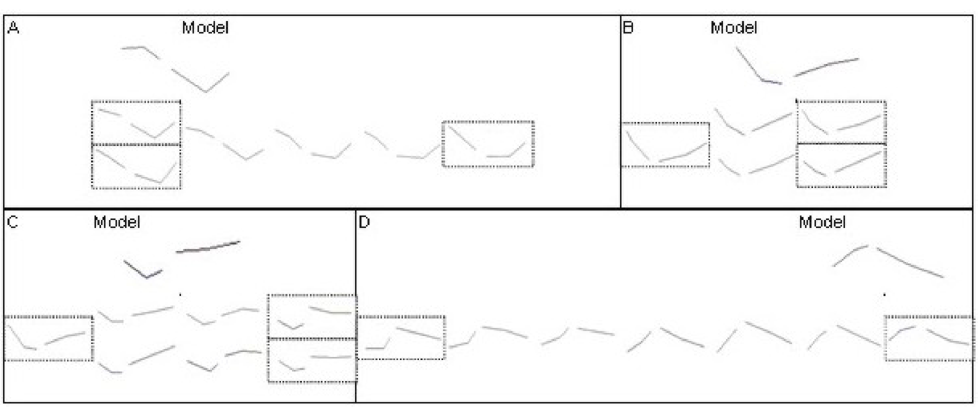


FIGURE 12. Illustration of the range of errors committed by the swimmers in the movement structure of legs and monofin in relation to the accepted model. Drawings show key elements of the structure of leg and monofin movements (described in Tab. 4 and marked: A, B, C, D) related to occurrence of errors (Tab. 4)

TABLE 3. Pearson's correlation coefficients estimated between values of errors committed in the analyzed cycles at distances of: 100 m, 200 m, 300 m, 400 m, 500 m, 600 m, 700 m, 800 m, 900 m and the horizontal average swimming speed achieved over analyzed distances. Factors are marked for all swimmers tested and arranged according to average swimming speed achieved at trial distance

SUBJECT	KAT	ATM	HME	HTE	SUBJECT	KAT	ATM	HME	HTE
M	–0.94	–0.99	–0.62	–0.99	P	–0.79		–0.96	–0.85
A	–0.99	–0.55	–0.72	–1.00	S	–0.66	–0.88	–0.90	–0.89
B	–0.71	–0.94	–1.00	–0.70	N	–0.77			–0.52

KAT – angular flexion of legs at knees; ATM – angular bend of tail of monofin
HME – angle of attack of distal part of monofin, HTE – angle of attack of entire area of the monofin

TABLE 4. Key elements in structure of leg and monofin movement established for possible errors in effective reduction of propulsion technique during monofin swimming

	KEY ELEMENTS OF MOVEMENT STRUCTURE	ERROR DESCRIPTION
A	Straightening of legs at knee joints at moment of placement of shanks parallel to pool bottom.	Resulting from over-flexion of the hip joint (placing knees too deeply down in relation to feet) propulsion transferred to surface of fin only through the shanks.
B	Final fragment of downbeat related to placing legs in straight position at knee joints to achieve extreme lower placement.	Leg straightening movement at the knees limited to the final part of phase, causing over-placement of legs in too deep position at the ending of the downbeat.
C	Lifting legs straight up at the knees to achieve the greatest flexion in middle of fin area.	Start of upbeat with feet too deeply immersed resulting in error from too large a movement to straighten legs.
D	Lifting legs straight at the knees to begin flexion of the knee joint.	Over-lifting of straightened legs preceded by initiation of flexion on the knees.

There is also a clearly defined relationship showing that the lower the scale of errors, the higher the average swimming velocity (Tab. 3). On the basis of the value of correlation factors we can determine that the proper flexion of the feet has the greatest effect on swimming speed. Next in importance is the proper range of the angle of attack of the entire monofin. The ranking concludes with the appropriate range of angle of attack of the distal part and angle of bend of the proximal part of the monofin. The results presented are arranged in a similar manner to the average values of the sum of errors, which are accepted as a measure of the difficulty in realizing the movement structure indicated by the model (Fig. 11, 12). This fact suggests an assumption that, the greater the influence on swimming speed, the more difficult it is to execute the proper movement within the limits of its parameter.

DISCUSSION

The results obtained suggest that, the proper flexion of the feet in relation to the shanks, had the greatest influence on swimming speed. This is the parameter which most differentiated the swimmers, in terms of speed achieved in the cycle, and which seems to be the most difficult element in the movement structure of monofin swimming. The character of the series that described the angular flexion of the feet in relation to the shanks, and the layout of errors committed within the limits of the feet displacement, were least similar to each other in comparison with other parameters analyzed. Only in the case of dorsal flexion of the feet did the errors observed have an effect on the execution of movement below the range laid out in the model. The high level of errors committed suggests a low level of control over feet movement during propulsion generation in the group of swimmers examined. The feet, as an active (fully controlled by the swimmer) element in the biomechanical chain, are the last link in the transfer of torque to the surface of the monofin[16]. Therefore, the correctness of this element of the movement structure plays, from an educational point of view, the most significant role in the process of generating propulsion.

The dominant role of the feet in relation to the shanks, in generating propulsion, was revealed in the results based on the construction of a neural network[17], as well as research on the factors favoring the maintenance of high intracycle speed in monofin swimming[18]. Among other factors of note, it is necessary to include the limiting of the feet is flexion during downbeat, as well as the necessity to initiate as soon as possible, upward feet movement. In the case of upbeat, it is suggested to delay initiation of downward feet movement and to limit their dorsal flexion. The general observation (not only in the group tested) of a tendency towards excessive flexion of the feet in downbeat, appears to be unfounded. Given such a conviction we can confirm the fact that, in the movement phases examined, significant overload of the muscle-ligament apparatus at the ankle joint occurred, which causes pathology[19]. The average value of errors committed by swimmers and the difference between these values, in the case of bend of the proximal part of the fin, as well as the other factors indicating bend of the monofin, are similar to one another. This may indicate that, bending of the tail of the fin, has an effect

16 Rejman M., Influencing of timing delay on monofin intra-cycle swimming velocity, [in:] Vilas-Boas J.P., Alves F., Marques A. (eds.), Xth International Symposium Biomechanics and Medicine in Swimming, *Portuguese Journal of Sport Sciences*, 2006, vol. 6, suppl. 2, pp. 85–88.

17 Rejman, Ochmann, op. cit.

18 Rejman, op. cit.

19 Rejman M., Frąckiewicz A., Overload of the ankle joints during monofin swimming – Mechanism and diagnosis, [in:] Zatoń K., Jaszczak M. (eds.), Science in Swimming II, AWF, Wrocław, 2008, pp. 196–202.

on the shape of its entire surface. It has been established that the tail is the place of torque transfer generated by the legs to the surface of the fin[20]. In this context, it appears that the tail is the key element linking the activity of the biomechanical chain, created by the leg segments (including the feet), with the segments of the monofin. The tail of the fin divides the chain mentioned into two parts: the part comprised of the leg segments, and the part comprised of the segments of the monofin[21]. From a biomechanical point of view we may understand that, the proper bending of the tail of the monofin, plays the most essential role in the process of generating propulsion.

The assumption pertaining to the overlapping transfer between specific links in the "leg – monofin" biomechanical chain, direct attention to the crucial role of the "foot – tail – surface of fin" link, in generating propulsion. In the context of achieving the objectives of the research, it is important to realize that controlling the proper activity of the examined links, as well as the proper process generating propulsion force, appears to play an essential role, essential in both biomechanical and educational aspects. Thanks to conscious, precise control of feet movement, the swimmer obtains the possibility to self-control and self-create monofin swimming technique. Optimal (model) flexion of the feet in downbeat, limits the bending of the tail of the fin, maintaining an optimal angle of attack of the proximal part of the fin. Optimal dorsal flexion of the feet in upbeat causes increased bending of the tail of the fin, as a consequence the angle of attack of the distal part of the fin, and its entire surface, obtain the optimum range in both phases of the cycle[22]. The factors supporting the maintenance of high intracycle velocity in monofin swimming seem to be the positioning of the feet and proximal part of the fin in one line. The immediate bending of the tail of the fin after initiating the upbeat and downbeat phases, limits the dropping of speed[23]. The angle of bend of the tail determines the angle of attack of the proximal part and entire surface of the fin[24].

The thesis formulated herein is reflected in the procedures undertaken to separate crucial sequences in monofin swimming technique (Fig. 11, 12, Tab. 4), and allows the conclusion that the optimal flexion structure of the monofin's tail, within the limits set out in the functional model, leads to the appearance of reserves aimed at achieving maximum swimming speed[25]. An examination of proper monofin swimming technique, in the category of transfer of torque generated by the legs to the monofin, allows the assumption that control over the precision of movement executed by the legs (through the feet), is transferred (through the tail) to the arrangement of the segments of the monofin and its entire surface. There are also results which show links between the structure of displacement of leg segments, and the displacement of the monofin. This relationship is dependant on the interaction between the influence of the proximal segments of the legs,

[20] Rejman, op. cit.
[21] Ibid.
[22] Rejman, Ochmann, op. cit.
[23] Rejman, op. cit.
[24] Rejman, Ochmann, op. cit.
[25] Ibid.

through the tail, with the proximal segments of the fin, and the influence of distal segments of the legs on the distal segments of the fin[26]. Research indicates that the lower the angle of bend in the distal part of the fin and its entire surface, the lower the bend in the tail and proximal part of the fin (i.e. a harder tail). The greater the angle of attack of the distal part of the fin and its entire surface, the more bend the fin has in the tail and middle parts (i.e. a softer tail)[27]. Generally, the impression is that the individual selection of fin, in terms of stiffness, favors the generation of torque by the leg, and its transfer to the surface of the monofin. This same individual choice of fin makes possible a degree of control, by the swimmer, over the proper execution of propulsion movements and creates conditions for using the monofin to gain maximal swimming speed.

The quality of torque transfer to the monofin, as a direct outcome of leg movement, is hydrodynamically submitted to the conditions of water flow over the surface of the monofin[28]. In the context presented herein, the change in mutual displacement of the feet, tail and the parts of the fin (through adequate changes in the nature of the flow velocity) leads to the formation of vortices – an additional source of propulsion[29]. In a stable vortex circulation, its energy also functions as the energy of an additional mass of water sloping away from the edge of the fin, at the moment of its change in direction[30]. Within this aspect, the dynamic system of transfer occurring in the change of position of the angles of the monofin's segments, changes the structure of water flow over the surface of the monofin, and appears to be crucial to effective swimming. As stated elsewhere[31], the achievement of maximum speed is supported by the displacement of the proximal part of the fin, to a position parallel to the direction of swimming, and suggests a longer outlay during the downward movement of its edge. The movement described is accompanied by the quickest possible initiation of downbeat movement of the distal part of the fin, leading to its positioning at the highest possible angle of attack. The descriptions presented from the results obtained form the basis for estimation of key elements in monofin swimming technique (Tab. 4 B, D – in the extreme upper and lower positioning of the feet, where legs are extended at the knee and the monofin is optimally bent at the tail and middle of its surface, and is placed near perpendicular to the direction of swimming). The research cited indicates this location of water reaction (drag and lift) as the main source of propulsion, as well as accompanying components in the form of energy from vortices, and the flexibility of the fin. The opinion of these authors is that positioning the distal part of the fin parallel to the direction of swimming plays the main role in the maintenance of constant speed in the cycle. The above research illustrates key elements of technique (Tab. 4 A, C – maximal bend of the distal and entire surface of the

26 Rejman, op. cit.
27 Rejman, Ochmann, op. cit.
28 Rejman, op. cit.
29 Ungerechts B.E., Persyn U., Colman V., Application of vortex flow formation to self-propulsion in water, [in:] Keskinen K.L., Komi P.V., Hollander A.P. (eds.), Biomechanics and Medicine of Swimming VIII, Gummerus Printing, Jyväskylä, 1999, pp. 95–100.
30 Colman, Persyn, Ungerechts, op. cit.; Rejman, Colman, Persyn, op. cit.
31 Colman, Persyn, Ungerechts, op. cit.; Rejman, Colman, Persyn, op. cit.

fin at the moment when the edge of the fin is changing its movement direction). In the sequences described, energy essential for swimmer propulsion, comes from the additional mass of water separating from the edge of the fin and the ensuing acceleration reaction.

The process of control and assessment of technique in monofin swimming demands from the coach, that information on errors be obtained and communicated to the swimmer on the basis of an objective method. Biomechanical methods fulfill the criteria of objectivity in the assessment of sporting technique[32], however an examination of technique, only within a biomechanical criteria, carries the risk of treating fin movement as a category of instrumental objective. That is why the tools of biomechanics and biomechanical assessment, need to be understood as indicators of the educational aims achieved. In this context, the use of biomechanics in the realization of educational objectives, creates the conditions for the rational steering of learning and the perfecting of swimming technique. The transmission of information between swimmer and trainer, related to errors and their elimination, is two-way in nature (feedback). This comes in the form of "movement answer" sent by the swimmer, after the earlier communication of the trainer, related to the error committed. Thanks to this feedback, the trainer also receives communication from the swimmer, allowing for the self-evaluation of educational effectiveness and an eventual correction, in the order to modify technique through the elimination of errors[33].

The most important characteristics of educational information are its accuracy and conciseness. In the case of communication between swimmer and trainer, the attributes mentioned are of particular importance. This is due to the nature of water as an environment not conducive to the transmission of verbal information. In consideration of the key technical elements of monofin swimming, being the result of the study, there are considerable practical applications to be gained. As with sequence movements, they allow for verbal generalization about movements executed, with an eye towards their correction, using the fewest number of words. The verbalization of key technical elements, in the form of descriptions of the key sequence, may be used in the memorization of the most important technical elements and for their commitment to motor memory[34]. Motor memory is the collection and storage of movement experiences through the act of imagining them. The full and correct imagination of newly taught or perfected motions is vital to their execution[35]. The changing of a retained movement – technique modification – is therefore a mental process, whose highest quality is fundamental for success in sports education.

In certain educational and sporting conditions, or in the perfection of swimming technique, verification of the motion imagination by the real movement is essential. In this regard, the knowledge of essential technical elements of monofin

32 Hochmuth G., Marhold G., Biomechanische Unteruchungsmethoden im Sport, *Theorie und Praxis der Körperkultur*, 1957, no. 6, pp. 1077–1085.

33 Schmidt R.A., Motor Control and Learning. A behavioral emphasis, Human Kinetics, 2nd ed. Champaign, 1988.

34 Schmidt, Lee, op. cit.

35 Schmidt, op. cit.

swimming, and the anticipation of errors related to it, plays a key role in the perception of kinesthetic impressions accompanying the movement of such a large monofin against the resistance of water. Research has established that monofin swimmers can clearly experience and differentiate kinesthetic impressions, while executing propulsive movement in the water[36]. This conscious perception of a kinesthetic impression may effect not only the efficient process of teaching a given physical activity, but its perfection in sport as well[37]. Therefore there is a basis for the opinion that the exchange of information of a multisensory nature between coach, swimmer, water and monofin – may have a determination on the speed of swimming.

CONCLUSIONS

The proper flexion of the feet in relation to the shanks, as well as the tail, plays the most significant role in the process of generating propulsion during monofin swimming.

The key technical elements of monofin swimming technique – encourage increased swimming speed – allow for precisely controlling executed leg movements (errors elimination), which through the feet, are transferred to the tail and to the consecutive segments on the surface of monofin.

Due to the identification of errors as well as key technical elements of monofin swimming, there is an opportunity for formulation of the proper verbal information concerning the structure of movement. This kind of information supplements the multisensory signals received by the swimmer individually from the water, and therefore make possible the improvement of the process of technical training in monofin swimming.

[36] Klarowicz A., Rejman M., Zatoń K., Estimation of kinesthetic differentiation capability by the monofin swimmers [in Polish], *Sporty Wodne i Ratownictwo*, 2009, no. 1, pp. 44–50.

[37] Klarowicz A., Zatoń K., Changes in kinesthetic differentation during program of fitness swimming for students, *Annales Universitatis Mariae Curie-Skłodowska Lublin – Polonia section D Medicina*, 2006, vol. 60, Suppl. 16, no. 291, pp. 258–261.

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Dynamic asymmetry of selected coordination abilities of the extremities in swimming children

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INTRODUCTION

The asymmetry of the human body has been subject to extensive research for many years. The laterality of the body is manifested in numerous areas of human activity including sport. Research studies into laterality have mostly been concerned with its ontogenetic development, the impact of practiced sports (symmetric, asymmetric) on the extent of lateralization or the issue of left-handedness in sport, e.g. Koszczyc, Starosta, Starosta et al., Wieczorek, Wieczorek and Hradzki, Wolański, Drabik, Wojtkowiak and Gabryelski, Mynarski, Ljach and Ljach and Witkowski[1].

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1 Koszczyc T., Morphological and dynamic asymmetry and the possibilities of their formation in children and young people of school age [in Polish], *Studia i Monografie AWF we Wrocławiu*, 1991, vol. 27; Starosta W., The problems of biased differentiation in human movement [in Polish], PTNKF, Gorzów Wlkp., 1990; Starosta W., Coordinated abilities and conditioning in team sports, [in:] Bergier J. (ed.), An International Conference on Science in Sports Team Games [in Polish], IWFiS, Biała Podlaska, 1995; Starosta W., Coordinated motor skills. Significance, structure, considerations and formation [in Polish], Międzynarodowe Stowarzyszenie Motoryki Sportowej, Warszawa, 2003; Starosta W., Rynkiewicz T., Strength differentiation in girls and boys, *Biology of Sport* , 2000, vol. 17, no. 3, pp. 207–216; Starosta W., Garbolewski K., Shooting at the goal in the light of functional symmetry and asymmetry in advanced water polo players, [in:] Osiński W., Wachowski E. (eds.), Research in physical education and sport [in Polish], *Monografie AWF w Poznaniu*, 2001, no. 333, pp. 211–214; Wieczorek M., The learning speed of complex movement activity and functional and dynamic asymmetry in ten year-old children [in Polish], *Wychowanie Fizyczne i Sport*, 2001, vol. 45, no. 1, pp. 105–114; Wieczorek M., Lateralization of the body in fourteen year-old youth [in Polish], *Annales Universitatis Mariae Curie-Skłodowska Lublin – Polonia section D Medicina*, 2005, vol. 60, supl. 16, p. 607; Wieczorek M., Hradzki A., Functional and dynamic asymmetry in 14 and 16 year-olds (comparative trials) [in Polish], *Acta Universitatis Palackiane Olomoucenis. Gimnica*, 2007, vol. 37, no. 1, pp. 51–61; Wolański N., Human biological development [in Polish], PWN, Warszawa, 1983; Drabik J., Biased differentiation of strength ability and quickness of the upper and lower extremities in children and young people [in Polish], *Wychowanie Fizyczne i Sport*, 1982, no. 3–4, pp. 27–41; Drabik J., Physical fitness in children from 7–15 years of age in the light of functional symmetry and asymmetry [in Polish], *Wy-*

An ambidextrous player who can promptly respond with his right or left hand or foot is a highly desirable asset from the standpoint of team play tactics. In individual sports, such as swimming, movement symmetry is highly emphasized with regard to the requirements of technique. The motor dominance of one side of the body may disturb one's swimming technique and force a swimmer to make compensatory movements[2]. The development of motor habits typical for each sport in younger children is aimed at the versatile development of motor skills and movement structure. Two out of the four competitive swimming styles (breaststroke and butterfly stroke) are symmetric, and the other two (front crawl and backstroke) are alternately symmetric. Swimming training for younger children should include aspects of play as well as aspects of versatile coordination development[3].

Dynamic symmetry and laterality are important issues in swimming, especially with regard to the symmetry of movement (full or alternate). A longitudinal research study, examining the effects of swimming training, at the general preparatory stages, on the dynamic asymmetry of coordination abilities, was carried out by Koszczyc in 1991. It showed that intentional symmetrizing actions in swimming training did not significantly change the extent and direction of dynamic asymmetry. The present study was aimed at verification of the results of Koszczyc's research by:

– determining the dynamic asymmetry of selected coordination abilities of the upper and lower extremities in children who train swimming as opposed to non-training children;
– seeking correlations between selected coordination abilities and sport results.

METHODS

The study sample comprised of 66 primary school children from the first and second forms (mean age 7.5 years). The control group (C) included 20 boys and 16

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[2] Jaszczak M., The influence of symmetrical exercises on dynamical asymmetry, [in:] Wolański W. (ed.), Biomechanics'06. International Conference, 6–8 IX 2006, Zakopane, *Zeszyty Naukowe Katedry Mechaniki Stosowanej Politechniki Śląskiej w Gliwicach*, 2006, no. 26, pp. 155–158; Seifert L., Chollet D., Allard P., Arm coordination symmetry and breathing effect in front crawl, *Human Movement Science*, 2005, no. 24, pp. 234–256.

[3] Rakowski, Modern swimming training [in Polish], Maciej Rakowski & Centrum Rekreacyjno-Sportowe Rafa, Rumia, 2008.

girls from the 3rd Primary School in Poznań who attended a basic school physical education programme. The swimming group (S) included 19 boys and 11 girls from the 14th Primary School in Poznań who attended a special school swimming programme consisting of three swimming classes and one general PE class a week. All PE classes in the schools under study were carried out by graduates of the University School of Physical Education.

The results of the present study were compared with those attained by Koszczyc in 1991, in his study on morphological and dynamic asymmetry in younger primary school children (aged 7.5). Koszczyc's experimental group had consisted of 80 boys and 39 girls and the control group of 88 boys and 27 girls.

The following research methods were used in Koszczyc's study as well as the present study:

– Body height and body mass measurements;
– Functional asymmetry test (arms and legs) Koszczyc[4].

Dynamic asymmetry tests:

1. Static balance test[5] – measuring the time of balancing on a single leg for the longest time possible. The subject places one foot on a T-bar beam, and the other on its base, holding the hands on the hips. A stopwatch is started when the subject begins balancing on one leg by taking the foot off the base of the beam. The stopwatch is stopped each time the subject loses balance and touches the base of the beam with his free foot, or release either hand on the hips. The maximum testing time is 60 s.
2. Precision of leg movement test[6] – consisting of putting, held between the big toe and the index toe, through a number of slots on a rack, in a designated sequence, as fast as possible.
3. Precision of arm movement test[7] – consisted of balancing a stick on the index or middle finger, while sitting on a chair, as long as possible.
4. Speed of leg movement test – tapping test[8] – consisted of moving the leg back and forth over a T-bar beam as many times as possible within 20 seconds. The subject sits on a chair with his arms sideways; the beam is placed along the center line of the chair. The test result is the number of cycles (movements of the leg back and forth) completed within the test time.
5. Speed of arm movement test[9] – consisted of moving 20 tennis balls from one basket to another as fast as possible. The subject kneels on the floor with the free arm resting on the thigh; the baskets are placed in front of the subject.

The obtained test results were subject to statistical analysis.

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4 Koszczyc, op. cit.
5 Fleishman E., The structure and measurment of physical fitness, Prentice-Hall, New Jersey, 1964.
6 Koszczyc, op. cit.
7 Sekita B., From research on motor differentiation between the left and right sides of the body in 18 year-old boys and girls [in Polish], *Kultura Fizyczna*, 1970, no. 7, pp. 29–63.
8 Fleishman, op. cit.
9 Koszczyc, op. cit.

RESULTS

The subjects' anthropometric profiles revealed no statistically significant differences among the swimming boys and girls (Tab. 1). The mean values of body mass and body height were similar; however, the differences were greater within the control group.

TABLE 1. Subjects' anthropometric profiles

	Girls				Boys			
	swimming		non-training		swimming		non-training	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Body height (m)	1.26	0.1	1.26	7.8	1.31	0.1	1.29	7.8
min–max	1.18–1.34		1.12–1.35		1.19–1.44		1.13–1.46	
Body mass (kg)	25.7	3.4	28.6	7.8	30.0	5.8	28.4	6.9
min–max	20.1–32.8		20.0–46.0		21.8–42.7		20.0–49.4	

The present study revealed differences between the swimming and non-training girls in dynamic asymmetry tests (Tab. 2). A slight, statistically significant difference, was noted between the static balance test results in the two groups. The non-training girls maintained balance on the right foot longer (3.8 s) than their swimming counterparts (1.7 s). The difference was statistically significant at $p < 0.05$. The results of the lower limb precision of movement tests were better in the swimming group, but the difference was not statistically significant. The rather insignificant standard deviations indicate fairly uniform results in this particular test.

The non-training girls featured better results in the precision of arm movement test than the swimming girls: 7.8 and 0.9 seconds, respectively. The differences between the mean results in the group of girls were statistically significant at $p < 0.05$ (left arm) and $p < 0.001$ (right arm).

TABLE 2. Results of dynamic asymmetry tests of coordination abilities in girls

	Swimming girls (N = 11)				Non-training girls (N = 16)			
	right		left		right		left	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Static balance (s)	1.7	1.7	2.1	2.1	3.8*	3.4	3.9	3.5
Precision of leg movement (s)	26.6	8.4	25.2	10.7	29.1	12.7	31.5	10.6
Precision of arm movement (s)	0.9	0.8	0.8	0.7	7.8**	8.8	5.7*	7.8
Speed of leg movement (number of cycles)	21.0*	2.4	19.2*	2.3	17.9	2.3	16.9	2.7
Speed of arm movement (s)	19.4	2.6	20.5	1.9	17.8	2.8	18.4*	2.4

* $p < 0.05$, ** $p < 0.01$

In the speed of leg movement test (Fleishman's tapping test) the swimming girls achieved better results than the control group. The differences between the two study groups were statistically significant at $p < 0.05$: on the average the swimming girls completed 21 cycles, while the non-training girls 17.9 cycles, within 20 seconds.

In the last test measuring the speed of arm movement[10] the non-training girls scored higher than the swimming girls. The differences between the groups in the tests of the left arm were only slightly significant at $p < 0.05$.

The measurements of functional asymmetry revealed predominant right-handedness and right-footedness in the swimming group. However, the percent of left-footed swimming children was higher (Tab. 3 a, b).

TABLE 3 a. Functional asymmetry of the arms and legs in the swimming group (N = 30)

	Right asymmetry		Left asymmetry		Unspecified asymmetry	
	N	%	N	%	N	%
Arms	29	96.7	1	3.3	0	0
Legs	24	80	5	16.7	1	3.3

TABLE 3 b. Functional asymmetry of the arms and legs in the control group (N = 36)

	Right asymmetry		Left asymmetry		Unspecified asymmetry	
	N	%	N	%	N	%
Arms	35	97.2	1	2.7	0	0
Legs	24	66.7	11	30.6	1	2.7

TABLE 4. Results of dynamic asymmetry tests of coordination abilities in boys

	Swimming boys (N = 19)				Non-training boys (N = 20)			
	right		left		right		left	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Static balance (s)	2.1	2.6	1.9	2.2	2.3	2.9	3.5	5.5
Precision of leg movement (s)	23.1	6.9	26.3	5.6	27.9	9.3	27.8	10.2
Precision of arm movement (s)	0.9	1.0	0.9	1.0	4.7*	7.8	5.4*	9.6
Speed of leg movement (number of cycles)	20.4***	1.3	19.1**	1.3	17.6	1.9	16.8	2.3
Speed of arm movement (s)	20.7	2.9	21.5	3.0	18.8	3.6	20.8	4.8

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Fewer statistically significant differences were found between the swimming and non-training boys (Tab. 4). The results of the static balance test were similar in the two groups of boys. The results of the leg movement precision test were higher in the swimming boys (right leg: swimmers – 23.1 s, non-training – 27.9 s) however, the differences were statistically non-significant. The precision of arm movement test revealed differences between the two groups of boys at $p < 0.05$ for both arms: left arm in the swimmers – 5.7 s, in the non-training boys – 0.9 s. In the control group the results were fairly dispersed around the mean value. The

10 Koszczyc, op. cit.

swimming boys were characterized by a higher speed of the legs as compared with the non-training boys (right leg – p < 0.001; left leg – p < 0.001). The swimmers performed Fleishman's tapping test faster than their non-training counterparts (20.4 and 17.6 cycles, respectively). The standard deviation points to the results closer to the mean value in both groups. No differences were found between the two groups of boys in the results of the arm speed test.

Koszczyc's study[11] had revealed significant differences between training and non-training girls in the leg precision movement test (Tab. 5): the swimmers performed the test (right leg) faster than the non-training girls (10.5 s and 11.9 s, at p < 0.001 respectively). The training subjects also attained better results in the speed of arm movement (right arm – 16.9 s as opposed to 18.2 in the control group at p < 0.001). The results of the remaining tests revealed no statistically significant differences between the study groups.

The boys in Koszczyc's study from both study groups produced very similar results of coordination abilities tests for the left and right extremities. No statistically significant differences were found between the groups of boys or the extremities (Tab. 6). The low standard deviation indicated only a slight diversity of the attained results.

TABLE 5. Results of dynamic asymmetry tests of coordination abilities in girls[12]

	Swimming girls (N = 39)				Non-training girls (N = 80)			
	right		left		right		left	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Static balance (s)	6.4	5	7	5.6	6.0	6.2	5.8	4.8
Precision of leg movement (s)	10.5*	1.9	12.1	2.8	11.9	2.8	13.2	3.3
Precision of arm movement (s)	1.4	0.6	1.3	0.8	1.3	0.8	1.2	0.7
Speed of leg movement (number of cycles)	22.0	2.0	20.8	1.8	20.9	2.2	19.8	2.2
Speed of arm movement (s)	16.2*	1.7	17.1	2.0	18.2	2.7	19.3	2.9

* p < 0.001

TABLE 6. Results of dynamic asymmetry tests of coordination abilities in boys[13]

	Swimming boys (N = 27)				Non-training boys (N = 88)			
	right		left		right		left	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Static balance (s)	5.3	2.7	4.8	3.4	4.9	3.4	5.0	3.6
Precision of leg movement (s)	12.8	2.7	13.4	2.5	12.9	3.1	14.3	4.2
Precision of arm movement (s)	1.8	0.9	1.5	0.9	1.5	0.7	1.3	0.6
Speed of leg movement (number of cycles)	21.5	2.0	19.8	1.9	21.0	1.9	19.7	1.9
Speed of arm movement (s)	17.1	2.4	17.7	2.6	18.1	2.6	19.0	3.3

[11] Ibid.
[12] Ibid.
[13] Ibid.

A comparison of the results in the present study and Koszczyc's study[14] reveals the closest similarity between the results of arm and leg speed of movement tests. The biggest differences were observed between the results of leg movement precision tests followed by static balance tests (Tab. 7 a, b). The results of the arm movement precision tests were similar in the swimming and non-training groups.

The comparison of the extent of laterality in both study samples[15] shows that the differences between the left side and the right side of the body are smaller in the swimming subjects than in the non-training ones.

TABLE 7 a. Extent of dynamic asymmetry in swimming and non-training boys[16]

	Koszczyc	Cyrak	Koszczyc	Cyrak
	swimming boys		non-training boys	
	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$
Static balance (s)	0.5	–1.2	0.5	0.3
Precision of leg movement (s)	–2.8	1.5	–0.6	–0.2
Precision of arm movement (s)	–0.2	–0.7	0.3	–0.04
Speed of leg movement (number of cycles)	1.7	0.8	1.7	1.2
Speed of arm movement (s)	1.1	–2.0	–0.6	–0.8

TABLE 7 b. Extent of dynamic asymmetry in swimming and non-training girls[17]

	Koszczyc	Cyrak	Koszczyc	Cyrak
	swimming girls		non-training girls	
	$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$
Static balance (s)	0.2	–0.1	0.6	0.4
Precision of leg movement (s)	–1.7	–2.2	1.6	1.2
Precision of arm movement (s)	0.2	2.1	0.1	0.2
Speed of leg movement (number of cycles)	1.1	1	1.2	1.6
Speed of arm movement (s)	1.1	–0.6	0.9	1.0

The present study also aimed to find correlations between selected coordination abilities and the sports results. The application of Spearman's rank correlation coefficient revealed that significantly better sports results were achieved by children with lower body mass and higher speed of the arms (Tab. 8).

The Mann-Whitney U test (Tab. 9) revealed lower results of the static balance (left side) and arm precision and speed (both arms) tests in the swimming subjects. The swimmers, however, attained better results in the leg movement speed test.

14 Ibid.
15 Ibid.
16 Ibid.
17 Ibid.

TABLE 8. Statistically significant correlation between body parameters of coordination abilities and sports results in training children

Parameter correlated with the sport results (boys and girls together)	Spearman's rank correlation coefficient
Body mass	0.37*
Speed of the right arm	0.42*
Speed of the left arm	0.54**

* p < 0.05, ** p < 0.01

TABLE 9. The Mann-Whitney U test results in the swimming and control groups

	Right Z	Left Z
Static balance (s)	–1.8	–2.1*
Precision of leg movement (s)	–1.2	–1.3
Precision of arm movement (s)	–2.4**	–2.4***
Speed of leg movement (number of cycles)	4.7***	3.8***
Speed of arm movement (s)	2.6***	2.5***

* p < 0.05, ** p < 0.01, *** p < 0.001

The observed high number of left-footed subjects (N = 15) led to a comparative analysis of right-footed and left-footed subjects, with the Mann-Whitney U test, which revealed statistically significant differences in the results of the right leg movement precision test and leg movement speed test. The left-footed subjects attained significantly lower results in these tests than their right-footed counterparts (Tab. 10).

TABLE 10. The Mann-Whitney U test results in left-footed and right-footed subjects

	Z
Precision of the right leg movement (s)	–2.24*
Speed of the right leg movement (s)	2.44*
Speed of the left leg movement (s)	2.59**

* p < 0.05, ** p < 0.01

TABLE 11. Number of children with right and left laterality in the swimming and control groups

	Better extremity test result			
	right	left	right	left
	number of swimming children		number of non-training children	
Static balance	12	15	10	24
Precision of leg movement	11	16	15	15
Precision of arm movement	7	20	22	14
Speed of leg movement	25	2	25	7
Speed of arm movement	17	11	27	9

Tab. 11 lists the numbers of children with right and left laterality in particular tests. In the static balance test more children, in particular from the non-training group, were right-footed. In the speed of movement tests a higher number of children with the predominant right laterality was revealed. On the other hand, more swimming subjects achieved better results in movement precision tests with their left arm.

The comparison of left-right footedness/handedness in five tests showed no statistically significant differences between the mean test results in the control group. In the swimming group, the only statistically significant difference between the right-footed and left-footed subjects, was noted in the results of the leg movement precision test ($Z = -2.90$, $p = 0.004$). The extent of laterality was greater in the right-footed swimmers ($\bar{x} = 10.2$ s) and lesser in the left-footed swimmers ($\bar{x} = 5.3$ s).

DISCUSSION

The aim of the study was to determine the extent of laterality and dynamic asymmetry of the extremities in swimming children, as compared with non-training children, and likewise compared with the results of a similar 1991 study by Koszczyc.

In the present study the children displayed differences in their coordination abilities. The non-training subjects attained better results (statistically significant) more often than the swimming subjects, especially in tests of the arms. The speed of movement, in particular the movement precision of the arms, was more significant in non-training subjects.

The static balance of the body was a parameter dominated by non-training girls. The better results were attained by the swimming children, in tests assessing the speed and precision of the legs. Swimming training methodology at a young age is particularly concerned with legwork, which has a visible effect on the results of the present study. In terms of speed and precision of the arms there are generally no decisively significant differences between the training and non-training subjects.

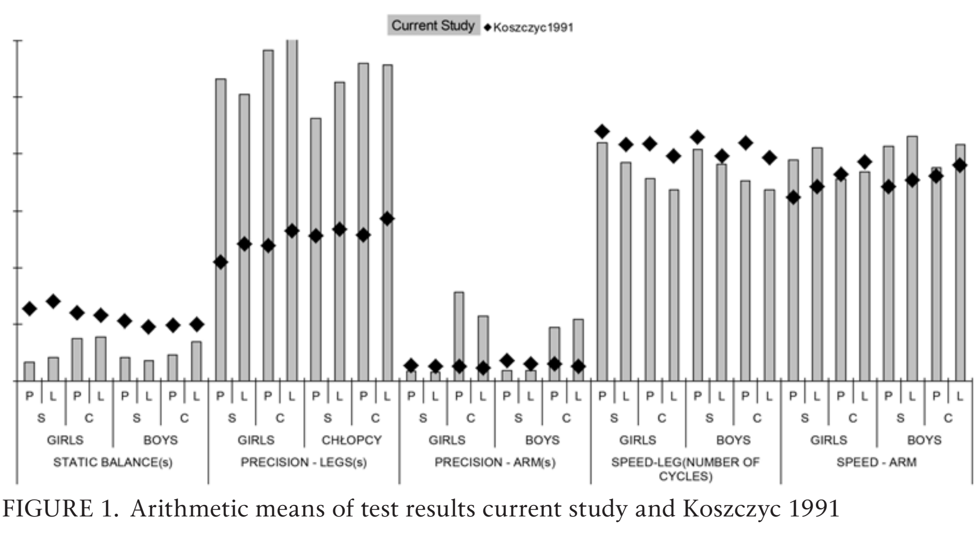

FIGURE 1. Arithmetic means of test results current study and Koszczyc 1991

These sometimes lower results by worse swimming children were not completely unexpected but were very interesting. Swimming is for children, more often an endurance type sport, than a speed or coordination effort. There is no movement coordination training. Children practicing sport sometimes are taller than others children and therefore, not as good in movement coordination.

The observed differences between test results from the present study and the Koszczyc's study from 1991 (Fig. 1), show that present-day children are characterized by worse precision of movement of the legs and static balance. It can thus be concluded that, the subjects from the present-day study, were worse in precision coordination movement tests of the lower extremities.

CONCLUSIONS

1. The substantial majority of children under study were right-footed and right-handed. Only in the precision leg movement tests was a significant difference noted between the extent of laterality in left-footed and right-footed swimming children.
2. The differences between the swimming and non-training subjects were more frequent and more significant among girls.
3. Non-training children attained better test results more often.
4. A correlation was found between the sports results and the speed of arm movement and body mass.
5. The comparison of the results of the present study, with those obtained by Koszczyc in 1991, shows that present-day children score lower in tests assessing precision coordination of leg movement. In all tests the present-day children scored decisively better than the subjects from the 1991 study.

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Different functions of the upper limbs in breaststroke swimming – a pilot study

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INTRODUCTION

Locomotion is an every-day activity performed by man. It may be defined as a motor activity which enables the body to relocate in the surrounding environment. Locomotion on land is based on performing alternate, cyclical lower limb movements. Even though they are frequently assumed to be symmetrical, the research results revealed that movement is really asymmetrical[1]. It is generally attributed to the existence of the asymmetries so characteristic to every man. Morphological asymmetry may be observed in different structures of the opposite limbs, dynamic asymmetry may be manifested in the difference of the forces generated by those limbs; while functional – in their functions[2]. During locomotion one lower limb propels while the other one stabilizes the gait[3]. During water locomotion the human body takes a horizontal position and it relocates due to the lower and upper limb movements. The movements in front and back crawl stroke are alternate, while in the breaststroke and butterfly, the mirror movements can be observed. The results of the research conducted on land revealed the tendency of the motor organ to perform mirror asymmetry movements. Movements which involve homogeneous muscles are easier to initiate and synchronize with high frequencies[4]. Perhaps the motor organ preferences may be explained by the fact that breaststroke swimming is the most favourable type of movement in water among those frequently applied the amateur swimmers. Locomotion in water is related to

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1 Arsenault A.B., Winter D.A., Marteniuk R.G., Bilateralism of EMG profiles in human locomotion, *American Journal of Physical Medicine*, 1986, vol. 65, no. 1, pp. 1–16; Herzog W., Nigg B.M., Read L.J., Olsson E., Asymmetries in ground reaction force patterns in normal human gait, *Medicine and Science in Sports and Exercise*, 1989, vol. 21, no. 1, pp. 110–114.

2 Koszczyc T., Machnacz W., The influence of direct training activity on the amount of morphological and dynamic asymmetry in young handball players [in Polish], [in:] Czabański B., Koszczyc T. (eds.), Didactics of physical education, AWF, Wrocław, 1995, pp. 235–247.

3 Sadeghi H., Allard P., Duhaime M., Functional gait asymmetry in able-bodied subjects, *Human Movement Science*, 1997, no. 16, pp. 243–258; Sadeghi H., Allard P., Prince F., Labbelle H., Symmetry and limb dominance in able-bodied gait: a review, *Gait and Posture*, 2000, no. 12, pp. 34–45.

4 Spijkers W., Heuer H., Kleinsorge T., van der Loo H., Preparation of bimanual movements with the same and different amplitudes: specification interference as revealed by reaction time, *Acta Psychologica*, 1997, no. 96, pp. 207–227; Sadeghi, Allard, Duhaime, op. cit.

receiving the stimuli which differ from those received on land. They result from different characteristics of both environments. Mirror symmetry movements are rarely observed during locomotion on land; those movements are frequently performed while swimming. The question can arise, if during mirror symmetry movements – breaststroke swimming – limbs can perform different roles. As the upper limbs are the main propulsion source during swimming (although, in the case of the breaststroke the opinions differ)[5] the purpose of this research was to identify upper limb function while swimming the breaststroke. It is expected that their functions, similarly to the gait, differ despite performing the same movements. The propulsive function may be manifested by generating greater forces[6]. While stabilizing function may be characterized with greater variability of movements which may be caused by an interference in stable swimming trajectory. Since the neuromuscular system regulates the senses[7], the elimination of some of them may restrict the stabilizing function[8]. It is expected that this will be observed as a decrease of the stabilizing movements of the movements.

METHODS

Nine adults participated in the research (3 women and 6 men) aged 22.3 ± 1.5. Their body weight and body height were 70.4 ± 14.5 kg and 178 ± 11 cm, respectively. Their timed of swimming over a distance 25 m was 22.1 ± 3.5 s. Seven of the subjects were right-handed, two of them left-handed. All the subjects swam a technically correct breaststroke. Five subjects had never practiced swimming, three of them practiced in primary school and one of them was an active competitor.

The hand surface is the main propulsion surface while swimming[9]. The value of the propulsive force is determined by the pressure differential exerted by water on the dorsal and palmar side of a hand[10]. Thus, two differential pressure sensors by Honeywell (USA) 26PCB type 5 were used during the measurement. The sensors were placed between the third and fourth finger of the right and left hand. They were applied to measure the difference of water pressures, resulting from the hand movement, exerted on the dorsal and palmar side of a hand. The depth

5 Seifert L., Chollet D., A new index of flat breaststroke propulsion: a comparison of elite men and women, *Journal of Sports Sciences*, 2005, vol. 23, no. 3, pp. 309–320; Prins J., Murata N., Stroke mechanics of swimmers with permanent physical disabilities, *Palestra*, 2008, vol. 24, no. 1, pp. 19–25.

6 Sadeghi, Allard, Duhaime, op. cit.

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8 Koszczyc T., The efficiency of propulsive movements performed by the leg only, when swimming breaststroke, *Zeszyty Naukowe AWF we Wrocławiu*, 1974, no. 16, pp. 57–64.

9 Takagi H., Shimizu Y., Kurashima A., Sanders R., Effect of thumb abduction and adduction on hydrodynamic characteristics of a model of the human hand, [in:] Blackwell J.R., Sanders R.H. (eds.), Proceedings of swim session, XIX International Symposium on Biomechanics in Sports, June 26, 2001, University of San Francisco, San Francisco, 2001, pp. 122–126.

10 Touissant H.M., Van der Berg C., Beek W.J., "Pumped-up propulsion" during front crawl swimming, *Medicine and Science in Sports and Exercise*, 2002, vol. 34, no. 2, pp. 314–319.

of the sensor immersion did not influence the level of the signal. The signal was recorded on a PC. A video camera was used to record the course of movement. It was placed 5 meters above the water's surface in the long axis of the research area. Synchronizing lamps were used to synchronise the signal, measured by the sensors, with the video recording. During the measurement they simultaneously emitted an impulse to both devices. The research was conducted in a 25 × 5.75 m swimming pool. Before the research the sensors were calibrated at the depth of: 0, 20, 40, 60, 80, 100 cm.

Subjects participated in three tests. In the entrance test the subject was to swim the breaststroke a distance of 25 m in the shortest possible time. On the basis of these results the level of the subject's swimming skills was determined. No pressure sensors and video cameras were used during that measurement. Participants started by pushing off from the wall of the swimming pool. In the next two tests the complete measurements were taken. The obtained results were further analysed. In the first test the subject was to swim the breaststroke a distance of 20 m, with medium velocity, using only upper limbs. During breaststroke swimming, lower limb movements may influence the performance of the upper limbs[11], thus only the upper limbs were used during the measurement trials. A pullbuoy was placed between the lower limbs so they could not generate any propulsion. The subject took a horizontal, streamlined position, with upper limbs straightened along the head. He was held by the shanks and positioned in the axis of symmetry of the research area. The subject started to swim after the grip was released. The second test was similar, with only one difference. The participant was wearing opaque swimming goggles and had stoppers in the ears. The participant was unable to determine his body position in relation to the borders of the research area due to the limited possibilities of receiving information from the senses. Hence, the subject's control of movement was limited.

The obtained results of pressure differentials in time $P(t)$ (Fig. 1) were filtered by a 4th order low pass Butterworth Filter. Then, they were synchronised with the recording. Next, the propulsion of the upper limbs in the subsequent cycles was determined. It was assumed that the upper limb propulsion phase starts when the limbs, extended forward, begin the movement to the sides and to the back. The propulsion phase ended when the arms stopped sweeping to the back. The first and second cycles propulsion phases were excluded from the analysis. An impulse of pressure differential ($\int P(t)dt = P \cdot \Delta t$) for the propulsion phase of each limb in both tests was computed. Then, the variation coefficient $\int P(t)dt$ for each participant, separately, was computed for both tests. To do so, the following formula was used:

$$VC = \frac{SD}{\bar{x}} \cdot 100\%, \text{ where:}$$

VC – variation coefficient of impulse of pressure differential;
SD – standard deviation $\int P(t)dt$;
$\bar{x}$ – mean $\int P(t)dt$.

[11] Jaszczak M., Zatoń K., Dynamic asymmetry of the upper limbs movements in 11 year old boys while swimming the breaststroke, *Human Movement*, 2011, vol. 12, no. 4, pp. 337–341.

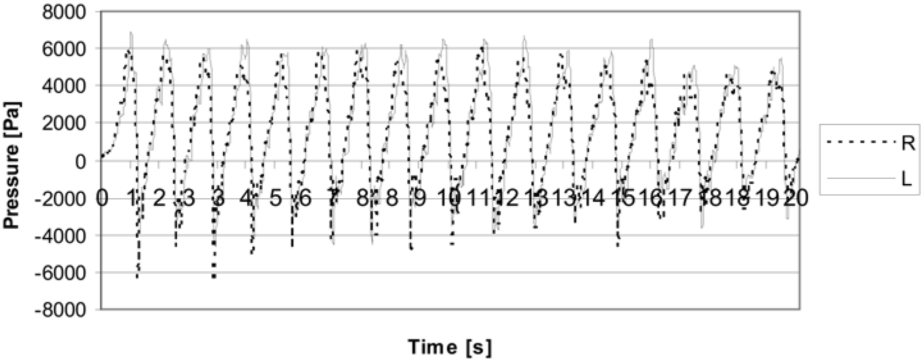


FIGURE 1. The example of pressure differential courses in time *P*(*t*) for the right (R) and left (L) limb

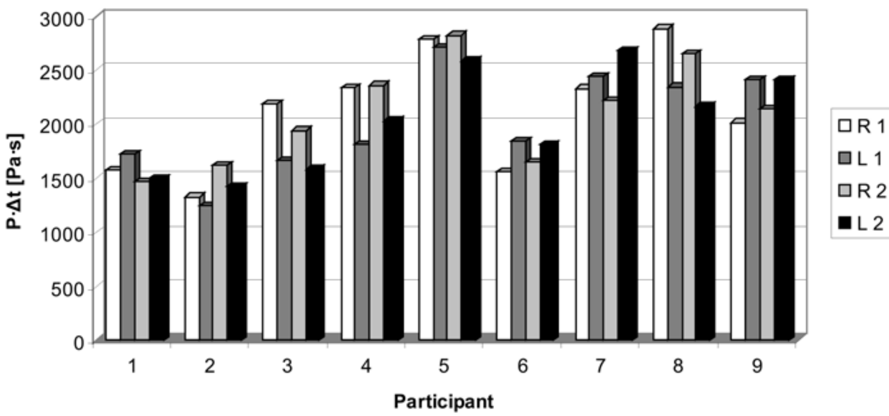
Means and standard deviations of pressure differential impulses for the right and left hand propulsion phase in both tests were computed. Before the application of parametric tests, normal distribution and *variance* homogeneity were examined. Then, the analysis of variance was applied to determine whether the propulsion values – expressed as ($\int P(t)dt$) – differed significantly between the limbs and tests. On the basis of mean values of impulses it was assume that the limb generating the greater values, functions as propulsion, while the second limb generating lesser values probably as stabilization. Next, the researcher verified the differences between the variation coefficients of impulses of both limbs. To do that, the test in which all senses were used, was applied. Then, it was examined whether sense limitation leads to changes in variation coefficients of the stabilizing limb. All the statistical tests were conducted by Statistica 9.0 (StatSoft, Inc., USA).

RESULTS

In the first measurement test, all the subjects swam 20 m, while retaining stable swimming trajectory. It means that they swam 20 m along the axis of the selected area. Movement trajectory of the participants oscillated in almost a straight line. In the second measurement test (with the limited participation of sight and hearing) only one person swam to the required point. It was a competitor who had regularly practiced swimming. Other subjects, after several cycles of stable swimming, changed the trajectory and headed to the side of the research area, reaching it between 10 and 14 meters.

Fig. 2 presents the intersubject differences of mean values $\int P(t)dt$ obtained for the right and left upper limbs. However, each subject had a limb which in both the first and second test, generated greater values differential impulse pressure. On the basis of the results obtained it can be assumed that this limb functioned as propulsion (Fig. 3).

The analysis of variance revealed significant differences for $p < 0.05$ ($F_{1, 470} = 36.11$) between the values of $\int P(t)dt$ obtained by the limbs with different functions. Mean impulses were not significantly differentiated by the tests applied, despite



R 1 – right limb, test with sense participation (no limitations)
L 1 – left limb, test with sense participation (no limitations)
R 2 – right limb, test with the limited participation of the senses
L 2 – left limb, test with the limited participation of the senses

FIGURE 2. Mean values of $\int P(t)dt$ for propulsion of the right and left upper limb of each subject in both tests, starting from the subject with the weakest swimming skills

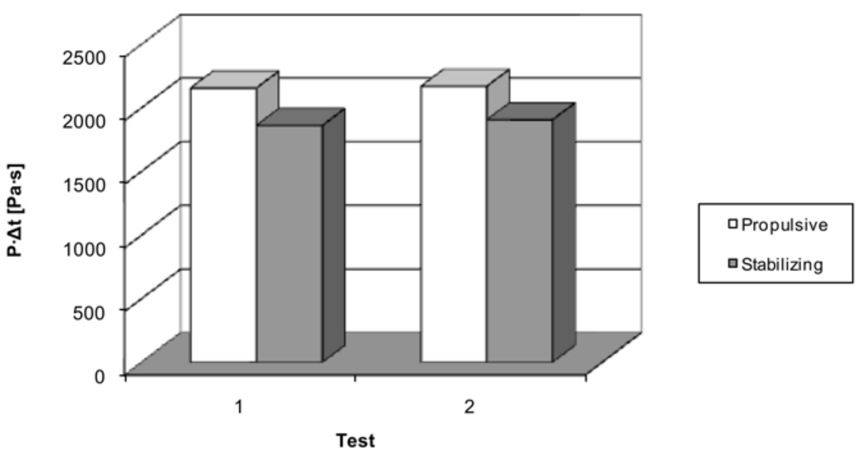


FIGURE 3. Mean values $\int P(t)dt$ for the propulsion phases of upper limbs having a propulsive and stabilizing function in the test with (1) and without (2) the participation of the sight and hearing

the involvement of sight and hearing. An interaction of two factors (function and test) revealed the lack of statistically significant differences between the impulse means of pressure differentials.

When all the senses were involved, the mean value of variability index $\int P(t)dt$ for a propulsive limb was 7.01 ± 2.03, and 8.65 ± 3.16 for the second limb (Fig. 4). It was assumed that the greater variability of the second limb may reflect its stabilizing function, although the obtained results did not significantly differ statistically for $p < 0.05$. The involvement of the senses was related to the changes in the value

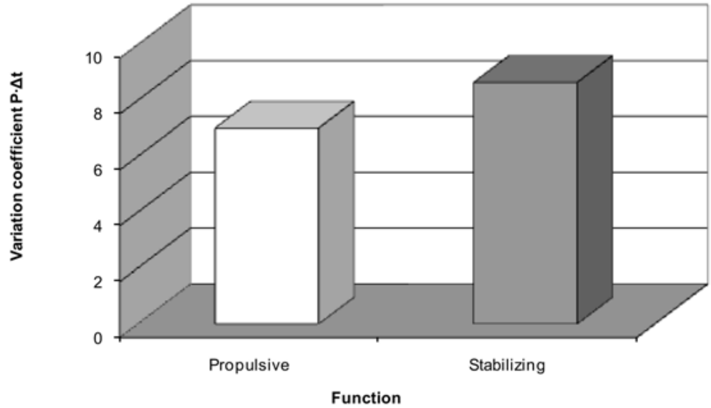


FIGURE 4. Mean values variation coefficient $\int P(t)dt$ for the propulsion of the upper limbs in the test with all sense participation

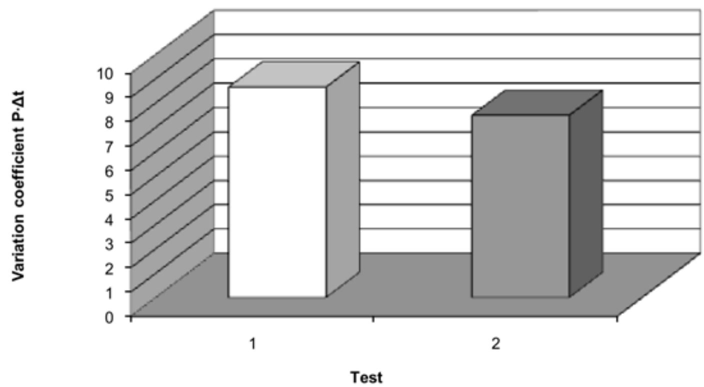


FIGURE 5. Mean values variation coefficient $\int P(t)dt$ for the propulsion of the stabilizing limb in two tests with (1) and without (2) the participation of the sight and hearing

of mean variability coefficient of the stabilizing limb. Due to sense participation, it fell from 8.65 ± 3.16 to 7.49 ± 1.74 in the second test, with limited sight and hearing (Fig. 5). However, the differences between them were not statistically significant on the accepted level.

DISCUSSION

This research aimed to identify the function of the upper limbs in breaststroke swimming. It was observed that each examined person had a limb which generated greater values of pressure differential impulse. It applied to both men and women, regardless of their swimming skills. It was always the same limb despite different involvement of sight and hearing. The obtained maximal values of pressure differentials are comparable to those obtained in the front crawl stroke[12]. During swimming, propulsion is generated by the difference of pressure between the dorsal and palmar side of hand[13]. Hence, it was assumed that the limb which generates greater values of impulse of pressure differential, was propulsive. In five out of nine subjects, the limb generating greater impulse, was the same as the one indicated by the subjects during the interview as being the preferred limb. However, it is not known whether the functional preference of the limb was in accordance with its force domination. The preferred upper limb might have been stronger and more precise. However, the distribution of these two characteristics between both limbs is not particularly rare[14]. Since the movements of the preferred limb are more exact[15], so the generation of greater impulse may be related to its greater precision – "a feel for the water". A high level of the feel for the water is related to the optimal hand position during propulsion phase[16]. It was assumed that the propulsive function is determined by the triggering of greater impulses of pressure differentials. However, it was not established which feature lies at its foundation: strength or precision. The answer to this question requires further research.

During swimming with the involvement of all the senses the limb which generated lower impulse presented smaller repeatability. It was expressed by greater means of variation coefficient and its standard deviation. However the comparison of the variation coefficients $\int P(t)dt$ of the propulsive and stabilizing limb were not statistically significant for $p < 0.05$. It was undoubtedly caused by the smaller amount of data which was due to the calculation of variability coefficient $\int P(t)dt$. Quite recently, biomechanists in sport have assumed that intersubject movement variability is a "buzz" and it should be eliminated[17] while athletes with great skills display greater repetitiveness of movements[18]. However, more often movement

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12 Toussaint, van der Berg, Beek, op. cit.

13 Takagi H., Wilson B., Calculating hydrodynamic force by using pressure differences in swimming, [in:] Keskinen K.L., Komi P.V., Hollander A.P. (eds.), Biomechanics and Medicine of Swimming VIII, Gummerus Printing, Jyväskylä, 1999, pp. 101–106.

14 Stokłosa H., Functional body asymmetry in experienced weight lifters and wrestlers, *Biology of Sport*, 1994, vol. 11, no. 1, pp. 65–69; Olex-Mierzejewska D., Raczek J., The human laterality phenomena: is the functional dominance on an equality with the strength dominance in upper limbs?, *Biology of Sport*, 2001, vol. 18, no. 3, pp. 238–244.

15 Carson R.G., Goodman D., Chua R., Elliott D., Asymmetries in the regulation of visually guided aiming, *Journal of Motor Behavior*, 1993, no. 25, pp. 21–32.

16 Ito S., Okuno K., A fluid dynamical consideration for armstroke in swimming, [in:] Chatard J.C. (ed.), Biomechanics and Medicine in Swimming IX, Université de Saint-Etienne, Saint-Etienne, 2003, pp. 39–44; Starosta W., Rostkowska E., Kokoszko J., The concept of "water feeling", its significance, determining conditions and formation in the opinion of coaches of various swimming sports, *Antropomotoryka*, 2003, no. 26, pp. 17–29.

17 Bartlett R., Wheat J., Robins M., Is movement variability important for sports biomechanics? *Sports Biomechanics*, 2007, vol. 6, no. 2, pp. 224–243.

18 Starosta W., The influence of participating in sports disciplines on the formation of symmetrical and asymmetrical kinesthetic sensations [in Polish], *Antropomotoryka*, 1994, no. 11, pp. 101–119; Fiłon M., Coordinated mechanisms for maintaining stable swimming technique, [in:] Zatoń K., Jaszczak M. (eds.), Abstracts of the 3rd International Symposium "Factors determining efficiency of swimming training and the learning-teaching process" [in Polish], AWF, Wrocław, 2006, p. 34.

variability is treated as a benefit: it is necessary to change the movement coordination (e.g. from walking into running). Due to the load of different areas, this decreases tissue damage, and facilitates adaptation to the exterior interference[19]. It seems that greater limb changeability, generating lower impulses, constitutes the response to the external interference. It was assumed that the limb manifests its stabilizing function this way. Probably, it is in this manner, that the motor organ corrects movement, in order to maintain stable swimming trajectory. Using the information received from all the senses, it compares the obtained effects with the expected ones and, using the stabilizing limb, it applies the necessary corrections. Therefore, in the first test, the variability of this limb was higher than the propulsive one. However, to do that, the visual signals are the most important[20]. In the second test the participants were wearing opaque swimming goggles and had stoppers in their ears. The lack of the information on body location in space obstructed the ongoing movement correction. It resulted in a disturbance in stable swimming trajectory – the subject swam towards the sides of the selected research area[21]. Lack of feedback interfered with motor control. Regarding the stabilizing limb, a decrease of variability coefficient values (both in mean and standard deviation) was observed. The obtained results revealed that the limitation of sense participation did not cause any changes in the functions of those limbs. Hence, it is possible that the functions assigned to them are quite unchangeable and the involvement of sight and hearing does not influence them. The published results show that no agreement has been reached in the debate on which of the two limbs is more repeatable (the dominating or non-dominating)[22]. The obtained results did not confirm the existence of such relationship. It seems that it is the term "dominant" (stronger, used more frequently) which requires revision.

The received results suggested the existence of a division in the functions of the upper limbs in breaststroke swimming. They are consistent with those obtained

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[19] Diedrich F., Warren W.H., Why change gait? Dynamics of the walk-run transition, *Journal of Experimental Psychology: Human Perception and Performance*, 1995, no. 21, pp. 183–202; James C.R., Dufek J.S., Bates B.T., Effects of injury proneness and task difficulty on joint kinetic variability, *Medicine and Science in Sports and Exercise*, 2000, no. 32, pp. 1833–1844; Minetti A.E., Boldrini L., Brusamlin L., Zamparo P., McKee T., A feedback-controlled treadmill (treadmill-on-demand) and the spontaneous speed of walking and running in humans, *Journal of Applied Physiology*, 2003, no. 95, pp. 838–843.

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[21] Kubisz E., Trial research in asymmetric movements of the extremities in swimming the classic style [in Polish], *Kultura Fizyczna*, 1962, no. 6, pp. 500–502; Koszczyc, op. cit.

[22] Annett J., Annett M., Hudson P.T., Turner A., The control of movement in the preferred and non-preferred hands, *Quarterly Journal of Experimental Psychology*, 1979, vol. 31, no. 4, pp. 641–652; Bagesteiro L.B., Sainburg R.L., Handedness: dominant arm advantages in control of limb dynamics, *Journal of Neurophysiology*, 2002, vol. 88, no. 5, pp. 2408–2421; Gutnik B., Degabriele R., Bailey K., Hudson G., Acquisition of the lateral inconsistency in voluntary behaviour of upper limbs in 12-year-old children during walking at moderate speed, *Journal of Comparative Human Biology*, 2006, vol. 57, pp. 51–71; Jaszczak M., Influence of practiced sport on the strength stability of the women's dominant and non-dominant upper extremity, *Polish Journal of Environmental Studies*, 2007, vol. 16, no. 5a, pp. 140–142.

by Seifert et al.[23] who observed such diversification of functions in the front crawl stroke. They stated that the dominating upper limb was propulsive while the non--dominating limb was stabilizing. The supporting function of the non-dominating limb in the front crawl stroke may be related to the exhaling performed during head turn. While in breaststroke swimming performance may be related to the compensation of the local asymmetries or maintaining stable and straight line trajectory. However, the existence of the differences observed between the performances of the upper limbs in breaststroke, to be seems specific for locomotion in natural conditions. The simulation of breaststroke swimming on the swim ergometer did not reveal either dynamic or kinetic asymmetry in the upper limb movements[24].

CONCLUSIONS

The conducted research suggests that:

- The function of the upper limbs may differ despite performing mirror symmetry movements,
- The propulsive function is related to generating greater impulses of pressure differentials, while stabilizing characterizes with their greater variability,
- The lower repeatability of limb movements is related to their stabilizing function, not to the subjects' preferences.

[23] Seifert L., Chollet D., Allard P., Arm coordination symmetry and breathing effect in front crawl, *Human Movement Science*, 2005, no. 24, pp. 234–256.

[24] Jaszczak M., The influence of symmetrical exercises on dynamical asymmetry, *Zeszyty Naukowe Katedry Mechaniki Stosowanej Politechniki Śląskiej w Gliwicach*, 2006, no. 26, pp. 155–158; Jaszczak M., The kinematical asymmetry during swimming on swimming ergometer, *Zeszyty Naukowe Katedry Mechaniki Stosowanej Politechniki Śląskiej w Gliwicach*, 2006, no. 26, pp. 159–162.